Article

Automated infrastructure: COVID-19 and the shifting geographies of supply chain capitalism

Weiqiang Lin

National University of Singapore, Singapore

Abstract

In recent years, geographers have evinced how infrastructure constitutes the bedrock of supply chain capitalism and its oppressions. This article interrogates how advanced automation – comprising robotics, artificial intelligence and software – is poised to politicize this infrastructural space further on the heels of the COVID-19 pandemic. Reflecting on COVID-19 developments, the article shows how logistics is turning to advanced automation to drive productivity outside labour, spur self-service consumption through digital technologies and contest labour's future. As automated infrastructure threatens to take hold, a configuration of exchange that increasingly places labour, but not profits, outside of capital's circulations will need to be challenged

I Introduction

A salient feature of late capitalism is its increasing reliance on logistics infrastructure to organize economic processes. While infrastructure has existed for a long time, critical scholars no longer blithely accept it as a neutral tool for 'development' (cf. Rietveld, 1989; Hesse and Rodrigue, 2004), but are concerned with its distributive logics and role in circumscribing the conditions of global production and consumption (Berlant, 2016; Easterling, 2014; Otter, 2017). In this respect, geographers have been at the forefront of delineating how infrastructure works to order and coordinate various logistical flows in spatio-political ways. While urban geographers point to the inequitable tendencies that artefacts like roads, pipes and grids have in

channelling urban resources to select communities (Furlong, 2011; Graham and Marvin, 2001; Heynen et al., 2006), others have dissected how infrastructure provides, on the planetary scale, a basis for long-distance production networks, trade and war (Cowen, 2014; Coe and Yeung, 2015; Khalili, 2020). These analyses signal that logistics infrastructure possesses profound circulatory powers that have a bearing on human subsistence and, most crucially, the basis for supply chain capitalism (Tsing, 2009).

Corresponding author:
Weiqiang Lin, Department of Geography, National University of Singapore, AS2 #04-17 Singapore 117570.
Email: weiqiang@nus.edu.sg

This article takes occasion of the COVID-19 pandemic to further reflect on how logistics infrastructures are currently evolving, as sudden ruptures and lurches during the crisis radically transform existing terms of global production and consumption. As Castree et al. (2020: 411–412) wrote at the start of the pandemic, 'COVID-19's legacy will leave no one untouched' and will set the stage for new eruptions 'of spatiotemporal unevenness'. This article posits that logistics infrastructure will (continue to) figure as a key locus where such unevenness will surface, but in ways that are subtler and harder to fault. Indeed, the disruption caused by COVID-19 presents unique external challenges that are capable of stopping – and reconfiguring – the 'engine of capital . . . for reasons other than its own internal contradictions' (Harvey, 2014: 9–10). Notably, businesses have had to endure immense pressures exerted by protracted lockdowns, mobility stoppages and forced social distancing, leading to seemingly foregone conclusions that the rules of logistics 'ought' to be rewritten for good. In this context, the COVID-19 pandemic might have provided a rare opportunity to rethink the constitution of infrastructural power, as well as the injustices entrained.

Chief of these changes is the way robotics, artificial intelligence (AI) and software – or advanced automation for short – are given renewed emphasis in imaginations of the post-COVID-19 world. To be sure, scholars in critical logistics have long acknowledged the role of automation in disciplining and reducing cost in work processes (Chua et al., 2018; Kanngeiser, 2013; Khalili, 2020; LeCavalier, 2016; Rossiter, 2016); researchers in digital geographies have likewise highlighted how self-operating systems, such as smart home devices and assistive transport facilities, are becoming common features of consumption landscapes (Coletta and Kitchin, 2017; Dodge and Kitchin, 2009). But here, I want to foreground not just the emergence of discrete 'coded infrastructures' in

everyday life (Kitchin and Dodge, 2011: 6), but a more *pervasive* shift in capital's architecture of circulation that is now attempting to usurp entire value chains with the help of technology. This far-reaching control based on what I call 'automated infrastructure' – an all-encompassing infrastructural framework marked by the primacy of virtualized transactions – contrasts with preponderant views that still stress the exploitation of people in the reproduction of logistical processes (Furlong, 2011; Lin, 2019; Simone, 2004). It affords an optic that shifts one's focus on the negotiations and interdependencies between humans and machines, to one that countenances the possible expulsion – or at least diminution – of the former within highly technocentric productive futures.

Such a transformation portends profound uncertainties for the future of work. In recent years, labour geographers and others have also begun interrogating the potentially conflictual relationship between labour and automation, as the rise of a new breed of intelligent machines threaten to remake 'the structures, conditions, and relations of everyday life' (Del Casino et al., 2020: 606; see also Wells et al., 2020). Infrastructure work – or work done to keep capital's myriad infrastructures moving – is particularly noteworthy as it is one of the last 'frontiers' where value is being created, often through the extraction of labour in labour-intensive processes such as distribution, transport and warehousing, as well as retail, finance and administration (Cowen, 2010, 2014; Rossiter, 2016). When even this labour becomes 'ossified and made concrete in the shape and form of a machine' (Kirsch and Mitchell, 2004: 696), the tertiary sectors of global production networks (GPNs), then, become hostile to workers as well (Coe, 2020), potentially affecting not just blue-collar workers, but also white-collar ones (Lee, 2018). It triggers a configuration of exchange that increasingly and unsustainably places waged work, but not

consumption, outside of capital's circuits, further heightening capital's contradictions (Harvey, 2014: 104). As advanced automation unexpectedly speeds up due to COVID-19, the future of labour seems to be marching exactly towards that unsavoury outcome.

To delineate the contours of this emerging pivot to automated infrastructure, the remainder of the article proceeds as follows. First, through a synthesis of literature in geography and beyond, the next section contemplates how critical scholars have regularly approached logistics infrastructures and their role in capitalist circulations. The third section then sketches out the role of automation in ruling and undermining logistical work/workers, as well as the latitude workers have in adapting to and resisting technology. The fourth, fifth and sixth sections provide readers with a picture of how a future of automated infrastructure might look like in the shadow of COVID-19. Drawing vignettes from the pandemic, I outline three distinctive ways in which automated infrastructure could reshuffle the terms of supply chain capitalism: through normalizing a culture of machine-dominated operations, enrolling (locked-down) consumers in logistics en masse and obliging future reimaginations of work. The final section concludes with a reflection on what a prevalent condition of automated infrastructure might mean for society.

II Logistics Infrastructure and Capitalism

Departing from earlier treatments of infrastructure as sunk developmental projects for the provision of services like transport and communications (Hesse and Rodrigue, 2004; Rietveld, 1989), the academy has lately re-fixed its gaze on the mechanics and implications of that provision. In particular, scholars today view infrastructure as the material-technological base of capital, serving as 'the architecture for circulation' and 'literally providing the undergirding of modern societies' (Larkin, 2013: 328). While mobility is key in the work of infrastructure, it is the solidity that it gives to movement that is crucial. As Berlant (2016: 394) writes, if structure is 'that which organizes transformation', then infrastructure is 'that which binds us to the world in movement and keeps the world practically bound to itself'. Such a conceptualization is echoed by Otter (2017), who ascribes infrastructure with comparable space-fixing powers. Depicting it as the building block of capital's 'technosphere', Otter (2017: 151) posits that the collective interaction of systems results in the 'infrastructuralization of space', which sets in motion particular dispositions in resource flows and exchanges.

In geography, one of the earliest ruminations in this vein emerged from the subfield of urban geography. Cities are ripe for such contemplations: not only because of their dense concentration of artefacts but also because urban experiences are highly contingent on the uneven network relations that infrastructures and delivery systems spin. Graham and Marvin (2001) were some of the first to offer such an analysis, contending that infrastructure is directly responsible for splintering cities into unequal landscapes of differentiated access and flows (see also Chu, 2014; McFarlane, 2018). Broadening the outlook, other geographers have looked at how infrastructure invokes extra-urban socioecological fluxes to sustain cities (Ekers and Prudham, 2017). Proponents of this view argue that infrastructure helps pull together political ecologies that link urban forms to distant biophysical sites for economic reproduction (Keil, 2005). From the way infrastructure channels commodities globally to feed metropolitan prosperity (Arboleda, 2016), to how it expends resources to realize conduits for trans-urban flows (Carse and Lewis, 2017), infrastructure plugs cities into a variety of capitalist relations to enforce what Brenner and Schmid (2015) call planetary urbanism.

The crux of logistical thinking, however, shines through the most in work that tackles the politico-economic drivers of global interconnections. In this regard, scholars have tended to adopt a more global outlook in the way capital works. Notably, writings by economic geographers have been instructive for explaining the development, since the 1970s, of GPNs. Charting the transition from post-Fordism to transnational coordination of production processes, these scholars argue that GPNs are a means for capital to organize flexible regional spaces that can help reduce cost, gain competitive advantage and maximize profit (Coe, 2012; Smith, 2015). Coe and Yeung (2015: 5) describe this strategy as a form of 'spatial fix', whereby 'lead firms in manufacturing and service industries seek lower-cost suppliers in international markets', through constructing networks of value activity across borders. Combined with 'regulatory frameworks, network integration, place marketing, labour relations and political climate', institutional and material infrastructures serve as anchor points upon which 'footloose' capital and resources can organize (Coe, 2020: 4).

Other geographers subscribe to a more agentic understanding of infrastructure, construing it as not just a mediator of movements, but a tool for extracting value through logistical circulation (Chua et al., 2018). While Easterling (2014) calls these artefacts the 'spatial products' of the global economy, Cowen (2020) insists that infrastructure allows capital to actively knit together a web of seemingly disparate spaces, transforming sites of production and consumption – for example, resource extraction zones, manufacturing centres and consumption markets – from discrete localities, into concatenated nodes that serve as a diffuse machinery of cross-border exploitation. Such a perspective is shared by Rossiter (2016: 1), who similarly describes delivery systems such as 'roads, railways, shipping ports, intermodal terminals, airports, and communications facilities and

technologies', and one might add distribution centres, retail outlets, trading houses and centres of administration, as intrinsically 'logistical' in nature. For Rossiter (2016: 1), '[l]ogistics infrastructure enables the movement of labor, commodities, and data across global supply chains' not as a matter of utility, but as an exercise that 'makes worlds' conducive for the efficient functioning of capital. Seen as such, infrastructure does not simply connect places or enable transnational business, but pivotally determines the conditions under which nodes and margins are created for strategic accumulation (Stenmanns, 2019).

The elongation of capital's production and consumption skeins via infrastructure is not an effortless process. As Cowen (2014: 1) avers, with 'logistics comes new kinds of crises, new paradigms of security, new uses of law, new logics of killing, and a new map of the world'. While technical disruptions of these vital systems are of perennial concern, it is infrastructure's labour that figures as a more menacing 'threat' to the diffuse operations of supply chain capitalism, seeing that workers have the capacity to strike, skive, subvert and upend production schedules. Yet, capital's relationship with infrastructure work is inseparable. First, logistics infrastructures are notoriously labour-intensive, requiring large numbers of people to attend to menial tasks such as packing, sorting, moving and responding to client requests (Furlong, 2011; Pickren, 2018). Second, the possibility of concentrating manufacturing processes in only a few (low-cost) economies have rendered logistics, and hence infrastructure work, an increasingly important arena of value extraction (Danyluk, 2018; Harvey, 2014). These twin phenomena make infrastructure a prominent locus of capital-labour exchange today, both enabling capital to reorganize and spread across space and altering the institution of work to one more and more contingent on logistics (Chua et al., 2018).

Some geographers have criticized the manner in which capital has incorporated this 'needful' labour within logistical systems. As time-sensitive operations, infrastructure work is particularly prone to treating the '"sensuous activity" of human beings' as 'raw material' to be metabolized efficiently and flexibly (Smith, 2007: 22). The estimation of people as essentially fungible and convertible has been flagged by labour geographers such as Strauss (2020), who cites tendencies in logistical activities towards labour exploitation, precarity and devaluation. Logistics scholars have further corroborated this view in their examination of port operations. While De Lara (2018) alludes to the use-and-discard, term-contract model of hiring truck drivers (typically comprising migrant and racial minority groups) at Los Angeles port, Khalili (2020: 208) assesses a harsher reality of overwork and repression among (again, migrant) port workers and seafarers in the Arabian Peninsula. Beneath their veneer as jobs generators, logistics infrastructures thus double as hidden set-ups that have a propensity to treat labour on grossly unfair terms. Rendering their human inputs 'flexible', they make workers 'subsume the frictions in the supply chain, and smooth out [any] glitches and bottlenecks' in relations to capital's circulations (Hepworth, 2014: 1132).

This discussion offers a perspective on how logistics infrastructures have risen to become a lynchpin of late capitalism. As anchors in the distributive networks of firms and supply chains (Coe and Yeung, 2015), they straddle a range of geographic scales and enable 'a suite of spatial practices aimed at facilitating circulation' (Chua et al., 2018: 618). For a long time, this extra-territorialization of markets has led to untold prosperity for capitalists, but it has also come at the expense of large contingents of workers who are absorbed, often at low cost, by a growing logistics industry that specializes in coordination and distribution (Harvey, 2014: 121). This model has been widely critiqued for

its injustice and 'deadliness' (Cowen, 2014), but it is, as we shall see, its unholy alliance with automation that has made infrastructure work particularly insecure and insidious. In the next section, I explore how automation has come to dominate the logistics business in recent decades, before considering how these technologies are setting the stage for a more pervasive automated future in the time of COVID-19.

III Logistics Infrastructure and Automation

Although spanning a wide range of technologies, there is general consensus among scholars that automation refers to the institution of some kind of 'self-organization' in machines and facilities. These technologies do not adhere to any singular definition or function, but sit astride a 'continuum' of applications that permit varying degrees of human non-intervention (Torrens, 2010: 138). In logistics, while some types identify more closely with mechanization, such as cranes and conveyor belts, others involve the digital processing of complex information, and the handling of evaluative tasks in lieu of humans. Whichever the case, 'robotics and automation systems' are able to 'distinctly rework, augment, and extend the capabilities and capacities of infrastructure networks' (Macrorie et al., 2021: 202), taking on new challenges across a wide range of logistical domains.

Computing software arguably figures as one of the first drivers transforming logistics infrastructures into more advanced forms of their mechanized selves. Described as '"coded" writings' capable of enacting a 'new kind of . . . semiotics' that displaces the role of human agency in spatial actions (Thrift and French, 2002: p. 310; see also Graham, 1998; 2005), software has drastically reduced the need for human oversight in all kinds of documenting, sorting and organizing activities. At first, many of these applications appeared as data

management systems, often targeted at speeding up port procedures (Cowen, 2010; Levinson, 2006; Wan et al., 1992) and/or streamlining traffic and consignment flows across transit spaces (Budd and Adey, 2009; Kitchin and Dodge, 2011). But with improvements in data analytics, these uses have been expanded to include intelligent action such as object recognition, profiling and predictive logics (Amoore, 2020; Krivý, 2018). In the span of three decades, software's coded possibilities have, as such, progressed from electronic messages and automatic signals, to a full-blown 'cognitive nonconscious' (Hayles, 2017) that is able to bond (logistics) space with all manners of coded intelligence (Ash et al., 2018). As logistics become more complex, so too have the digital powers that abet them.

One particularly insidious use of software has been to turn logistical workers into targets of such data management and prediction. In a bid to align labour with capital's goals, some logistics infrastructures have resorted to using technology to surveil and police workers' conduct. Kanngieser's (2013) work on the 'tracking and tracing' of warehouse and delivery personnel through a combination of Radio Frequency Identification tags, voice recognition systems and Global Positioning System telematics is instructive in this respect. Criticizing how technological systems are deployed to ensure the 'expedient circulation of capital' along supply chains, Kanngieser's (2013: 595) analysis foregrounds the security and disciplinary cultures that are developing around logistical artefacts, and the intents of those measures to smooth out unwanted irregularities and slow-downs through live monitoring of workers. Similarly, Rossiter (2016: p. 8) asserts that 'software' has so infiltrated systems of logistics that 'new subjectivities of labor' – not as humans but legible records – are being produced through an exertion of 'protocological control'. By this, he signals how protocol and discipline are subtly instilled in workers, through applying

surveillant power/knowledge on them and their movements. To the extent that these technologies seek to synchronize labour time with capital's productive timeline, they also serve to actively demean and dehumanize the value of infrastructure work.

Then, there are the autonomous robots that have recently pushed the automation envelope in logistics even further. While LeCavalier (2016) writes about 'inventory pods' that help pick and move items in warehouses without human assistance, Herrmann et al. (2018) observe the burgeoning rise of driverless vehicles in transporting people and goods across and between factory yards, seaports, airports and even cities. These robots and robotic technologies are potentially game-changing as they aggregate, for the first time, a wide array of 'smart' capabilities, ranging from sensors and prosthetics to algorithmic logic to machine learning to cloud computing (see Amoore; 2020; Crampton, 2016; Furlong, 2021; Zook and Blankenship, 2018). They not only appropriate code on a far larger magnitude than before; they also do so in ways that mimic humans in terms of their adaptability to non-repetitive situations and capacity for actuation (Macrorie et al., 2021). By blurring the boundaries between humans and non-humans, robots inhabit the space of the 'cyborg' *par excellence* (Haraway, 1991), enabling logistics infrastructure to be more resilient to the threat of resistant labour (Khalili, 2020).

These developments mirror wider debates in labour geography and labour studies about the changing relationships between humans and non-humans at work. In particular, the acquisition of organismic-like qualities by machines has prompted some scholars to argue that advanced automation – characterized by AI and robotic autonomy – is stoking a revolution that will displace more jobs than in any technological revolution of the past (Lee, 2018). Since the mid-2010s, economic studies and think-tank reports have been rife with predictions that the

rate of job replacement could rise to as high as 50 per cent in the next two decades (Dengler and Matthes, 2018). For Pierce et al. (2019: 90), the said trajectory threatens to tip the balance over into a broad-based systemic shift that makes 'disemployment', rather than 'ordinary unemployment', a permanent feature of the economy.

These prognoses paint a grim picture, but they are, in some ways, also not new. As Harvey (2014: 99) writes, '[t]he need to facilitate speed-up and acceleration of capital circulation in all its phases, along with the need to "annihilate space through time", has spawned an astonishing range of technological revolutions . . . [throughout] capital's history'. Because of this precedence, labour scholars caution against overemphasizing the cannibalistic nature of today's automation. Richardson and Bissell (2019: 278), for example, posit an alternative 'micropolitical understanding of skill', which provides latitude for labour 're-skilling' or 'up-skilling', as workers adapt (yet again) to automation and get redeployed to positions further up the value chain. Closer to logistics, Gregson et al. (2017) present a case of how port automation is ridden with frictions, requiring workers to skilfully navigate imperfect data flows and the 'everyday geographies of automation' (Kinsley, 2018: 159; see also Adler, 1990; Bissell, 2018, 2021). Indeed, as Lynch and Del Casino (2020) assert, technological introductions are not always antithetical to labour. Rather than a situation of machines attaining absolute domination, multiple forms of agency and intelligences, straddling the human and nonhuman, could coexist simultaneously, to constitute a 'dynamic unfolding' of relations (Hayles, 2017: 25).

Furthermore, labour has not been passive towards capital's attempts to outbid them. As labour scholars contend, technological changes of the past have typically bred discontents, more often than not culminating in labour resistance and class action (Silver, 2003). Such mobilizations of collective agency are commonplace in logistics too. While Ellem (2016) exemplifies a case of mining workers striking against imminent changes to their work and workplace because of automation, Anderson (2015) elucidates how logistics workers in India and Turkey took aim at the choke points of transnational companies and their commodity flows to demand more rights (see also De Lara et al., 2016). These episodes are indicative of the limits of technological revolutions even at implementation, as workers are capable of fending off undesirable futures through collective bargaining. While automation does raise the spectre of redundancy and job rotation in favour of certain vocations such as coders, computer experts, designers and data scientists (Bastani, 2019; West, 2018), the actual diminution of work has so far materialized in more uneven ways.

Nonetheless, it would be erroneous to conclude, therefore, that such remedial actions are sufficient to balance out automation's encroachment. As Danyluk (2018: 636) reminds,

> labor-saving technologies and new business practices introduced during the logistics revolution have had devastating impacts on transportation and distribution workers, who have been made to bear many of the real costs of cheap shipping in the form of low wages, harsh working conditions, and precarious employment.

Various authors, moreover, point to the recent role of subcontracting in weakening labour unions, as well as the banding together of corporate and state actors to ensure the smooth circulation of goods despite the occurrence of strikes (Benvegnù et al., 2018; Folkers and Stenmanns, 2019). The propensity for technology to become ever more pervasive (and intrusive) has only added to these troubles, making it difficult for workers to mobilize without attracting personal retributions. In this context, the COVID-19 pandemic might have been an untimely event for labour, seeing that it has further emboldened automation's adoption. By dint of the unprecedented ways it has unfolded,

COVID-19 might have remodelled global logistics space, and constructed an infrastructural framework that is altogether more automated, and post-exploitative.

IV Automated Infrastructure as Productivity

An outbreak that has upended the world, the COVID-19 pandemic has not only wrought havoc on global supply chains but has also triggered a response among countries to lean more heavily on advanced automation for logistical solutions. In China, where the outbreak originated, technological trials to cushion the effects of large-scale community lockdowns was in full swing by February of 2020, as robots and drones were deployed for meal, grocery and medical supplies deliveries (Hu, 2020). This knee-jerk turn to automation is significant: not because the technologies are new, but because of the sudden normative acceptance of the same as a productive substitute for cocooned (and often ultimately retrenched) workers. While, before COVID-19, capital had pursued the defensive use of robotics and AI – including robotic dollies and cranes (Gekara and Thanh Nguyen, 2018), 3D printing (McKinnon, 2016), autonomous ships (Levander, 2017) and even algorithmic trading bots (Beunza, 2019) – in concert with labour, it is now envisioning a viable form of productivity through automation alone.

This overhaul of attitudes towards automation's productive use should not be underestimated. Indeed, a number of logistics infrastructures are starting to gear towards such a high-automation future after just 1 year. Consider the aviation sector. Whereas an army of (mostly) migrant or elderly workers used to service the menial logistical needs of airport terminals, warehouses and hangars (Cresswell, 2006), the pandemic has made as many as 350,000 aviation employees redundant by the fall of 2020 (Jasper and Weiss, 2020). In their stead, there has been an expansion in interest in robotic solutions among airport managers looking to minimize 'high-risk contact' at these gateway infrastructures (Dube et al., 2021; Zeng et al., 2020). Besides novelty gadgets such as autonomous cleaners, humanoid guides and follow-me trolleys, some airport operators, such as Norway-based Avinor, are experimenting with end-to-end automated travel experiences supported by biometric check-ins and voice activated systems that no longer require any 'interpersonal contact' or 'support from agents' (Amadeus, 2020).

Likewise, in the movement of cargo, seaports from China to Russia are turning to block-chain technologies and the Internet of things to resolve supply chain bottlenecks as well as to safeguard the integrity of goods during the pandemic (Zhuckovskaya et al., 2020). At a time when 'truck drivers and dock workers are restricted due to social distancing' and lockouts (Jeevan et al., 2020: 230), slowing productivity has necessitated recovery plans that bank heavily on 'smart' technologies to maintain 'safe and secure infrastructures' and borders run by fewer humans (Dodds et al., 2020: 292). These trials and practices support a paradigm shift in the production and distribution of goods, which both extends pre-existing dependence on automation and strives towards a self-sustaining 'technosphere' (Otter, 2017) that can survive in spite of labour impairments. Whereas automation used to serve the function of bulwarking logistics infrastructures against the 'unruly worker' – and their 'willful acts of laziness, sabotage and refusal' (Rossiter, 2016: 26) – it is now reframed as a protector of the same, keeping people safe from disease, while keeping the wheels of logistics turning.

This clamour to intensify the automation of supply chains has spread to urban mobility infrastructures as well. Like their international counterparts, the proclivity towards machine-led urban logistics takes occasion of new operational realities created by COVID-19. Repeated mass stay-home orders have spawned demand

for logistical conveyances that utilize, in lieu of human couriers, 'contactless' transport systems, including self-driving cars, sidewalk robots, shuttles and drones (Lee and Frandino, 2020). In China, the appropriation of these robotic solutions during the height of the crisis had reached an unprecedented scale and scope, with hundreds of Baidu, JD and Meituan autonomous vehicles roaming public roads for the first time, carrying out cleaning and delivery services for immobilized populations (Hu, 2020). To overcome intermittent road closures around Wuhan, JD had further developed intelligent route planning systems that could dynamically time logistical sorting processes with fluid transport flows with little human intervention (Cao, 2020). Securing micro-movements within the warehouse, Amazon in the US also commissioned new design work, this time, for autonomous mobile robots capable of recognizing, grasping and packing items into boxes (Seitz, 2020). A feat once thought unnecessary due to the availability of cheap labour (LeCavalier, 2016), that capability became imperative after large outbreaks were discovered among workers in 50 of the company's fulfilment centres. These 'robotic applications' construct a norm that champions infrastructures apt for staying productive in '"hostile" environments where it is difficult for humans to function safely' (Chen et al., 2020: 239). While delivery robots and autonomous vehicles are not new (Herrmann et al., 2018), the rapid rollout of these technologies, across multiple locations and domains at once, has fuelled imaginations of an urban logistical landscape that contrasts sharply with previous reservations about automation's 'pharmakological' or socially disruptive nature (Bissell, 2018: 60).

Against this backdrop, profound renovations are underway in infrastructure's already-troubled relationship with labour (Cowen, 2014; Khalili, 2020). Although it is unlikely that humans would be completely extricated from logistical processes, recent developments suggest the advent – and normalization – of a new type of logistics infrastructure that reckons workers to be too vulnerable, and therefore, in need of minimization. To be sure, supply chain capitalism and manufacturing's offshoring and mechanization have already disempowered locationally fixed blue-collar workers for decades (Coe and Yeung, 2015; Tsing, 2009), leaving logistics as one of the last bright spots of employment. Advanced automation risks extinguishing even that avenue of livelihood, denying infrastructure workers what used to be a resolutely labour-intensive sector. The examples above signal the beginnings of just such a deepening appetite for 'touchless' and 'contactless' technologies that were once pursued discretely (Ellem, 2016; While et al., 2021). With labour now seen as not only wilfully disruptive but also epidemiologically an 'uncertain bet' (Nichols, 2020), owners of infrastructures have found a reason to redouble investments in robotics and AI to bridge any productive gaps caused by future pandemics.

This is a trend that is unlikely to abate, seeing that current investments will have a 'binding' effect on the long-term morphologies of infrastructure work (Berlant, 2016). While prevailing research is careful to point out that humans – especially in the form of cheap labour – will remain crucial to exploitative and manual logistical processes (Gutelius, 2015), the protractedness with which COVID-19 ensued has rendered at least part of their replacement both necessary and palatable. Indeed, if the ongoing economic recovery is any indication, logistics companies are intending to keep their workforce lean even with improvements in business outlook (Maersk, for example, expects to cut 2000 jobs despite improving cargo volumes in 2021), leaving most attrited workers the invidious option of waiting to be reabsorbed in lower value jobs. Perversely, this situation increases chances of a structural shift that precisely results in the 'disemployment' of labour (Pierce et al., 2019), even as global supply chains recuperate

and galvanize themselves with fewer humans. As artefacts turn into sites of technoscience resurgence, critical infrastructure research must also begin to rethink the place of the infrastructure worker in the post-COVID-19 era – not that they would disappear (machines still need some maintenance workers), but that pervasive automation might simply not require the same number of hands (Bastani, 2019).

V Automated Infrastructure as Self-Service

As a framework that oversees all transactions in the economy, automated infrastructure is potentially more omnipresent than what can be observed in overt industrial processes. If the end-goal of supply chain capitalism is to encourage consumption and thereby profit from it, businesses have had to conceive of new ways to deliver their products to customers during the pandemic too. Indeed, with social distancing, homeschooling and mass work-from-home arrangements becoming widespread (Rose-Redwood et al., 2020), infrastructures that provide effective B2C (business-to-consumer) services like advertising, local distribution and sales are necessary to materialize profits. These revamped artefacts are to serve as new interfaces (Ash, 2015) between capital and consumers, while adjusting to the fact that frontline staff may no longer be able to serve consistently as safe 'gates' (Nusselder, 2009) for capital exchange.

This shift in retail logistics portends new geographies of desire and fulfilment, which have moved increasingly from the material to the virtual realm. While formerly a terminal end of supply chains that required large expenditures of workers, retail has been undergoing transformation even before COVID-19, taking advantage of a range of what Kitchin and Dodge (2011) call 'code/spaces' to automatically tag, organize, manage the inventory of and carry out transactions in consumer goods.

Boosted by ecommerce, the Internet has further disrupted the norms of retail work and its infrastructural spaces, with several geographers pointing to the gradual replacement of physical stores – along with their labour and even some products like books – with online equivalents (Anderson, 2012; Wrigley and Lowe, 2014). COVID-19 has arguably opened the floodgates to this development, by shutting down entire communities, hollowing out city centres and decimating footfall in one fell swoop. Tellingly, Fortune magazine reported a record closure of 12,200 stores in 2020 in the US alone (Wahba, 2021), with tens of thousands more expected to shutter by the end of the pandemic (Danziger, 2020). In their place, businesses are turning to online platforms and Uber-style smart apps to retain customers. Fitted with algorithmic add-ons such as location mining, machine learning and multimedia outreach (Leszczynski and Kitchin, 2019), these digital emporia have not only resurrected, but at times even exceeded pre-recession projections of, sales (Huang, 2020). They have unleashed the power of platform consumerism (to paraphrase Barns's (2020) notion of platform urbanism), where purchases can be transacted routinely without human contact.

The acceleration of platform consumerism during the pandemic is an important step towards building a self-service automated infrastructure that closes the loop of virtualized logistics from beginning to end of product cycles. If initially motivated by survival and compulsion, global experimentations with platform buying, especially among affluent and millennial consumers, has demonstrated the real possibility of making remote purchasing the primary mode of, instead of another option in, retail. The scope of automating this stage of logistical circulations, moreover, does not just stop at the usual range of durable or digital goods this time, but has spread to such unlikely candidates as restaurant meals, magic shows

and (tele)yoga classes (see Nagendra, 2020; Yang et al., 2020). With unprecedented numbers of consumers now corralled into the habit of platform buying, COVID-19 has but introduced a new standard for mass – yet individually executed – transactions, short-circuiting the need for traditional middle persons between producers and consumers.

Such an unregulated approach to retail changes the arithmetic of infrastructure work again: this time, through a double move of outsourcing logistical work to every consumer, and replacing retail jobs with lower value ones in the deliveries sector. On the former, Ritzer and Jurgenson (2010: 18) have argued that the binary between production and consumption is a false one, seeing that capital has long striven 'toward putting consumers to work – turning them into prosumers' who are complicit in the production process. Thanks to the pandemic, 'prosumption' has grown to become more prevalent, as businesses seek to retain their customers through retail apps and social media, constantly interacting with them through highly personalized content (Sheth, 2020). Concomitantly, product placements now excessively suffuse through once-free services such as Google searches and YouTube videos (see Amoore, 2020). Platforms thus behave as semi-robotic intelligences that conduct, cajole and transduce home-based consumerism on-the-go (Dodge and Kitchin, 2005), while making users work harder for capital's circulation. As Richardson (2020: 625) further reflects, platforms function 'to connect supply and demand such that this can be understood as an automatic process . . . and a flexible spatio-temporal arrangement that occurs through the calculated coordination of . . . different actors'. More than ever before, COVID-19 has turned consumers into willing logistical workers of themselves, as well as detailed profiles for companies to mine and sell to (Murakami Wood and Ball, 2013).

A second attack that platform automation has levied on infrastructure work pertains to the deepening of a gig economy of delivery personnel who are temporarily (self-)employed to meet the sudden surge in home-based orders during COVID-19. Often composed of workers displaced, in the first place, by earlier rounds of automation's (and the pandemic's) attritions (Deloitte, 2021), these workers are (re)commodified as fungible *mobile* assets operating in an open market devoid of 'basic employment protections like minimum wages and sick pay' (Katta et al., 2020: 204). They are what Paché (2020) calls 'microentrepeneurs' at their own disposal, who partner with third-party logistics and intermediary companies on a freelance basis (Barratt et al., 2020), to fulfil low-value logistical functions. As Coe (2021: 12) writes, the explosion of B2C ecommerce accelerated by COVID-19 'has led to more and more products being shipped directly to consumers on tight timelines', raising the spectre of long hours, excessive pace of work and not to mention the risk of viral exposure among these agents. Algorithmically policed by the same platforms in terms of their efficiency, discipline and service quality, Veen et al. (2020) argue that these workers are becoming the new subjects of capital's panopticon (see also Van Doom and Badger, 2020; Newlands, 2021). Whereas logistical labour used to be surveilled in warehouses and sorting centres, the pandemic boom in platform consumerism has caused a new generation of infrastructure workers to be born, now to be managed across entire urban milieus.

Critical infrastructure research is well placed to interrogate how these shifts in the organization of retail are changing the nature of supply chain capitalism at its consumption end. From the way consumers/prosumers are enrolled en masse as managers of their own (lockdown) inventories, to the way an army of delivery personnel are suddenly in demand to fulfil orders during times of relative immobility (and unemployment), this trend of using virtualized instructions to sustain business has given rise to an automated mode of buying of a scale never

before attained. While it is uncertain whether such mediated consumption would persist beyond COVID-19, the potential permanency of current habits – from large-scale work-from-home arrangements to the acquired appreciation of online conveniences – cannot be discounted. By changing the rhythm of people's routines, and infiltrating the spaces of everyday consciousness through apps and social media, an automated infrastructure composed of platforms has arguably begun a work of socializing subjects into a new lull of self-service transacting, if at the expense – *and* with the help – of large numbers of gig delivery workers ejected from their former roles.

VI Automated Infrastructure as Future

At the heart of automated infrastructure is simultaneously a question of power and a struggle over the future. Changing perceptions of 'productivity' in logistics and acquiescence towards 'self-service' are certainly logical reactions in the midst of a pandemic, but their expansion, continuation and escalation are sustained by a distinct political will exceeding the here and now. Indeed, there are signs that capital is already preparing to solidify a different global economy informed by a pandemic-induced 'fourth industrial revolution' (Lee and Park, 2020). European Central Bank President Christine Lagarde, for one, proclaimed that the pandemic would spur a shift towards greater digitization and automation and shorter supply chains (Horobin and Rajbhandari, 2020). In the private sector, tech companies are responding by touting 'the efficacy of other forms of labor' than the manual type, championing a different (read: superior) class of 'technological or technoscientific work' overseen by elite citizens (see Kirsch and Mitchell, 2004: 697). While the direct supplanting of humans with machines is never complete, COVID-19 has emboldened these elite subjects to accelerate research into

new forms of advanced automation to achieve more resilient (if also exclusive) supply chains.

The valorization of this technoscientific work during, and beyond, COVID-19 connotes an attempt to undercut labour power, by making automated infrastructure a locus of domination. Buoyed by the emergencies of COVID-19, design works in new applications such as those explored in earlier sections have lately been held up as new niches of 'valuable' work in the post-pandemic world. Notably, national governments including not just the US and China, but also developing countries from India to Indonesia, have begun urging industries to adopt 'key technologies such as Internet of things, AI, automation, robotics and sensor technology' to ensure supply chain security into the future (Neo, 2020). Whereas the contention before was between mobile capital and immobile labour, a new class tension is now emerging between the technoscientific elite and the infrastructure worker who is now not only at risk of redundancy but is also encouraged to retrain and reinvent themselves to avoid becoming obsolescent. Problematically, this disruptive technological intrusion pitches the success of one labour class against another, drawing the two into a worker-talent competition centred on automation (Klumpp, 2018). Where one form of labour is reckoned to be 'dead', capital demands 'fresh living labor' to uphold a new line of work (Kirsch and Mitchell, 2004: 696).

Exacerbating the situation is the non-commensurability of the two types of work. Not only are the skill sets between them non-transferable, technoscientific work also tends to benefit a select few (West, 2018). Indeed, the field of automation remains a highly exclusive and male-dominated domain, tending both to recruit in uneven ways, and to inscribe, at the product level, a masculine logic onto many of its applications (Robertson, 2010). Boyer and England's (2008) work on automatic banking – albeit an older artefact now – exactly shows how technological formulations can have a

conditioning effect on the (gendered) provision of services and their expected clientele (see also Siemiatycki et al., 2020). Furthermore, automated infrastructure works through matrices of race in its redistribution of labour. Design hubs like Silicon Valley thrive on the inflow of cheaper and/or foreign (commonly Indian) technicians (Xiang, 2007), whose innovations later get re-exported back to the Global South in sectors such as agriculture and transport, in turn having adverse effects on livelihoods there (Lee, 2018). Reshuffling the global workforce through these conduits, automated infrastructure is set to aggravate what Fuchs (2014: 122) calls a 'disjuncture economy', causing some to lose their autonomy as machines and AI increasingly centralize logistical decision-making.

Yet, it is imperative to recognize that these futures can produce contradictions and crises, and therefore possibilities for challenge and change. As Harvey (2014: 104) points out, 'if social labour is the ultimate source of value and profit, then replacing it with machines... undermines the possibility of profit'. Put alternatively, crimping waged work in favour of logistics infrastructures that are highly automated has its paradoxes, as it destabilizes a majority of workers' long-term ability to socially reproduce and sustain their consumption. Over time, an unsustainable loop of hyper-extraction that concentrates more and more surplus value in the hands of capitalist elites, highly skilled technoscientific workers (Kirsch and Mitchell, 2004), and, at best, technicians of automation who manage to re-skill in time is the result, potentially spelling 'catastrophic effects upon the economy' (Harvey, 2014: 104).

Already, infrastructure workers are seeking to overturn this accelerated march towards automation, as the pandemic piles on furloughs and retrenchments and reduces aggregate incomes. Reminiscent of previous labour withdrawals in the face of excessive technological intrusions (Cowen, 2014; Ellem, 2016), logistics personnel are taking advantage of capital's lingering (but increasingly provisional?) reliance on them as 'essential workers' (Salazar, 2021) to negotiate for fairer pay, more humane hours and better health safeguards. While port workers in Melbourne and Rotterdam have walked out in protest of increased terminal automation under the pretext of COVID-19 (European Transport Workers' Federation, 2020; Wallis, 2021), Amazon's warehouse workers striked, in November 2020, against the company's sped-up work demands, even as the ecommerce giant became a trillion-dollar corporation on the backs of rising platform sales (Thomson et al., 2020). These struggles affirm the enduring bargaining power of labour, as automation technologies, to date, still lag the material intricacies and corporeal demands of infrastructure work (Chua et al., 2018; Khalili, 2020); but they also raise important questions about the future efficacy of such class actions, as walkouts only serve to steel capital's resolve to reduce its human dependencies, after COVID-19. Indeed, while workers may now enjoy some leeway to navigate between logistics' operational needs and technology's limitations, automated infrastructure – built, in time to come, to fend off disease, and secure supply chains – risks hastening their redundancy.

There is then the possibility of adaptation and experimentation as a response to technological change (Bissell, 2021; Richardson and Bissell, 2019). As earlier discussed, labour geographers have contributed to thinking through how humans and machines need not always exist in antagonistic ways, but can aid one another more collaboratively and ambivalently (Adler, 1990; Bissell and Del Casino, 2017; Kinsley, 2014, 2018). COVID-19, with its mainstreaming of various once-optional automation technologies, arguably presents fresh opportunities for labour to renegotiate their relationships with machines, as much as the pandemic itself has threatened to diminish their relevance. This does not mean a

capitulation to capital's (convenient) call for human resource retraining and reinvention but entails a proactive posture to reclaim what Lynch (2020a) calls 'technological sovereignty' through alternative, counter-hegemonic modes of everyday use and (re)interpretation. By constantly availing space for techno-social reformulations and ground-up initiatives, visions of other futures – such as in the creative use of smart apps (Elwood and Leszczynski, 2018), or autonomous vehicles (Yeo and Lin, 2020) – can help disrupt 'the abstract logics of digitization', while challenging 'hierarchies of technological knowledge and expertise' from below (Lynch, 2020b: 3). These responses will be especially pertinent in steering the future of automated infrastructure, ideally away from its current tendencies to sideline and dispose of labour, towards a less cannibalistic coexistence. Rather than to promote machinic substitution, it is a chance to rethink how an economic future that works for both workers and capital alike can be carved out.

VII Conclusions

This article has drawn on developments during the COVID-19 pandemic to shine a light on the growing inclination towards automated infrastructure in supply chain capitalism. It adds to critical infrastructure debates by surfacing the role that robotics, AI and software play in supporting, improvising and reimagining economic circulations in a time of crisis. While automation is certainly not new, what this article wants to highlight are the distinct threats and dominations that a pervasively automated infrastructure could usher in when the said technologies are taken to extremes. As COVID-19 prompts an infrastructural framework marked by the primacy of virtualized transactions, another set of spatial rules governing capital's architecture of circulation inevitably comes to the fore.

The triple moves explored in this article, involving automated infrastructure as

productivity, as self-service and as visions of the future represent a few of those rule changes and evolving geographies. I have demonstrated how these trends, made salient by COVID-19, fold into one another to create an unstable economic configuration that concurrently undermines infrastructure work(ers), enrols consumers in platform logistics and leaves the future of supply chain capitalism highly contentious. Although the transmutation of logistics infrastructures into completely 'people-less' machines is unlikely, COVID-19 has opened Pandora's box to some unprecedented conditions – of mass layoffs, improvised technological solutions, increased virtual transactions – that potentially foment a capitalist space that is disjunctural and disruptive to labour (Fuchs, 2014; Harvey, 2014).

Such a perspective advances critical infrastructure research in at least two ways. First, it underscores the importance of recognizing the pandemic's profound effects on worldly narratives about advanced automation. Indeed, robotics, AI and software technologies are now being embraced much more readily than before and are valorized for purposes beyond simply assisting, regulating and disciplining infrastructure work (Kanngieser, 2013; Rossiter, 2016). Instead, they are now being liberally experimented with as self-sufficient actors that can survive the most severe of lockdowns, potentially denting some of the last vestiges of labour-intensive work in logistics. With industries warming up to the idea of using robots and AI to oversee intelligent and complex tasks such as driving, sorting, mining, building and even retailing, automation has left large numbers of vocations increasingly insecure, whose holders struggle to reskill in time. Almost in a race to the bottom, technology seems to have done more to relegate (most) labour to the lowest value denominator in supply chains (e.g. gig economy delivery workers), than to reorganize logistics for the better.

Second, this article also wants to call attention to the possibilities for challenge and change despite the currently disfavourable employment climate. Whereas COVID-19 has so far painted a grim economic picture for infrastructure workers, nascent experimentations with automation during the pandemic has also introduced new opportunities for labour (and consumers) to redefine how they envision their futures alongside technologists and designers (Lynch, 2020a, 2020b; Bissell, 2021). Such attempts at reappropriating invented products for alternative uses is not easy, but neither is it a wistful position of counter-hegemony, seeing how in times past unsuspecting technologies – from dating apps to TikTok marketing (Cockayne et al., 2017; Hudders et al., 2021) – have been recast by ordinary people for uses they were not originally intended for. In the context of logistics, the race to find such creative gaps in automation is even more urgent, seeing that they can have 'real' implications on the value and preservation of live(lihood)s.

To be sure, the world is closer to the beginning of these portentous shifts than to the end. The height of the COVID-19 crisis has only offered a first glimpse of what the global economy could look like when labour was abruptly withdrawn. While some of the initial shock of the pandemic will ebb, the event will leave an indelible impression concerning the practicality of (some forms of) automated infrastructure; but it will also highlight the human pain and anguish involved in the sudden mass retrenchments experienced in the spring of 2020. In order to prevent capital from taking further advantage of what is epidemiologically already a human tragedy, it is paramount to take automated infrastructure to task as more an opportunity to take advantage of for/by the people than a reason for capitulation. On its part, the paper hopes to have provided some starting points to chip away at a still-hazy future everyone should be wary of.

ORCID iD

Weiqiang Lin https://orcid.org/0000-0002-5484-0860

Supplemental Material

Supplemental material for this article is available online.

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Author Biography

Weiqiang Lin is a human geographer interested in mobilities and the infrastructures of moving. Employing cultural geographical approaches, his work examines the myriad ways in which contemporary society is mobilised in practice. His recent research includes the production of airspaces in Southeast Asia; discursive and technological framings of air logistics in Singapore and China. as well as labour and automation in four of Asia's biggest international airports.