Infrastructures, intersections and societal transformations

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A B S T R A C T

There is renewed and increasing interest in understanding the part that infrastructures play in societal transformations, especially in response to the various challenges of climate change. Studies that focus on these issues tend to examine infrastructures in isolation from each other, and tend to work with evolutionary accounts of incremental change punctuated by short periods of radical innovation. This paper questions both these abstractions. Using four empirical cases, it directs attention to intersections between infrastructures at specific times and places, highlighting the dynamic qualities of infrastructures-in-use, and conceptualising societal transformations as outcomes of these intersections. Four forms of intersection are elaborated – co-constitution, adaptation and threading through, historical layering, and coexisting configurations. Instances of each are used to illustrate some of complex and often ambiguous processes through which infrastructures interact. The paper ends by outlining implications for future research and for interventions by policy-makers and others seeking to influence the ways in which infrastructures intersect.

1. Introduction

Following Star's (1999) call for greater attention to the 'boring thing' of infrastructure, an infrastructural turn (Amin, 2014) has unfolded across the social sciences. One important strand of research within this turn has sought to conceptualise the role of infrastructures in societal transformations in systems and configurations that underpin services like heating, mobility and storage of food (e.g. Bolton and Foxon, 2015; Frantzeskaki and Loorbach, 2010). To proceed at all, researchers have to work with various abstractions and simplifications that make it possible to grasp their topic. Apart from the tendency to examine infrastructures separately from the practices they enable, studies of infrastructure and societal transformation are often characterised by two other features. The first is adherence to a model of change in which long periods of gradual or incremental evolution are punctuated by shorter periods of fundamental or radical change, linked to a privileging of developmentalist accounts in which systems and infrastructures are thought to progress through generic steps and stages. Second is the tendency to consider one infrastructure at a time and examine it in isolation from others (e.g. Hawkey, 2015; Rogers et al., 2015; Webb, 2016). This has substantive and practical implications for conclusions about which actors are deemed responsible for change and intervention, and for the types of recommendations that are drawn out.

Abstractions are inevitable in thought and research but they can

hinder rather than aid understanding of the complexity of the world (Schwanen, 2018; Whitehead, 1925). For instance, the tendency to consider one infrastructure at a time overlooks the extent to which everyday practices and social arrangements depend on constellations of intersecting infrastructures. One method of discovering whether and how understanding is limited by the enacted simplifications is to experiment with different concepts and models. This generates alternative forms of knowledge and can produce different insights for policymaking and governance. In taking such an approach we unpack fresh lines of enquiry, inspired by Star and Ruhleder's contention that 'infrastructure is a fundamentally relational concept. It becomes infrastructure in relation to organized practices' (Star and Ruhleder, 1996: 113).

Drawing on four empirical cases, we examine some ways in which infrastructural roles and practices intersect, and how these intersections are constituted at different scales and periods of time. The situations we select concern the co-constitution of infrastructure for cycling in Copenhagen; 'threading' an infrastructure for on-street charging of electric vehicles through Oxford's Victorian infrastructure; the interplay of infrastructural arrangements layered on top of each other in Manchester's 'Northern Quarter'; and interweaving infrastructural systems of diet, food storage and electrical power in Hanoi and Bangkok.

Other empirical cases could have been chosen and a greater number presented, but collectively the examples with which we work allow us to show how different abstractions can be used to animate analysis of

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the role of infrastructures in societal transformations. Taking heed of Star and Ruheleder's (1996) definition, we offer situated and nuanced accounts of how infrastructural relations develop and change in concert with each other and with social practices and institutions. This approach generates alternative interpretations of infrastructural evolution. Instead of highlighting processes of zero-sum competition, strong path dependencies and transition pathways unfolding in relatively uniform ways, we underline the indeterminacy that is a feature of situations in which multiple infrastructures intersect.

In working with these ideas and methods we have three main aims. One is to abstract differently and so provide a counterweight to dominant methods of representing infrastructures in studies of societal transformation and urban development. The second is to describe distinctive forms of intersection amongst infrastructures, practices and institutions. The forms we consider include relations of co-constitution; adaptation and 'threading through'; historical layering; and co-existing configurations of infrastructural systems. The third ambition is to articulate some of the implications of attending to infrastructural interactions for research methodology, for policy, and for other types of intervention. We suggest that would-be interveners, amongst others, should engage in permanently reflexive forms of governance regarding the dynamic relations between infrastructures and practices rather than understanding their role as that of helping networks and systems move from one 'phase' or stage of development to the next.

2. Infrastructural intersections

2.1. Common abstractions

Infrastructures – road, rail, electricity, gas, water, broadband – are typically conceptualised as 'large', extensive and somewhat durable systems. This leads some to claim that they have certain techno-economic characteristics (scale, collective provision and sunk costs) and that these matter for how and when such systems develop and change. A key assumption in writing on societal transformations is that infrastructures evolve gradually and exhibit strong path-dependence. For example, Franteskaki and Loorbach claim that in 'areas such as energy, mobility, health-care or food provision, infrasystems [infrastructures and associated institutions] have been developed over a period of decades, that were optimized to fulfil societal demands in the most effective and efficient way.' (Frantzeskaki and Loorbach, 2010: 1293) It is simultaneously assumed that eras of evolution are punctuated by shorter periods in which infrastructures and related institutions experience some kind of step change, in which simmering competition between incoming and incumbent systems culminates. A classic example of such change is the transition from horse-drawn carriage to car-enabling mobility infrastructures in which needs and values shifted rapidly due to increasing internal and external ('landscape') pressures on the incumbent mobility system and the internal momentum of the car 'niche' (Geels, 2005b).

This style of understanding infrastructure development fits linear accounts of sequential phases, exemplified by Bolton and Foxon's (2015: 541) infrastructure lifecycle model which distinguishes between the distinct phases of 'system building and expansion', 'system expansion and 'momentum', 'stagnation and inertia' and 'system renewal and transition'. Their model, which again assumes periods of incremental change punctuated by moments of fundamental change, is justified with reference to evolutionary economics, industry dynamics and the sociotechnical approach of Geels and colleagues (Bolton and Foxon, 2015: 541). One might add socio-ecological systems theory (e.g. Holling, 2001) to this list.

Alongside these linear, sequential accounts there are equally prevalent claims that meanings of 'improvement' and of societal function are interwoven rather than existing independent of infrastructural change. In other words, even during periods of apparent stability there is an ongoing transformation of both infrastructures and the 'needs'

they meet. Depending on the time-scales considered it is possible to argue that while incremental infrastructural optimisation progresses with regard to the 'societal demands' of the day, the 'functions' of infrastructures 'co-evolve' with them, and are therefore inherently unstable. For example, the 'multi-level model' of systems in transition (Geels, 2005a), particularly in later formulations (Geels and Schot, 2007), includes nuanced understandings of evolution in which 'surviving' innovations develop symbiotically, and change the context in which they exist. Similar forms of evolution exist at different scales, meaning that transitions in regimes are seen as an outcome of competition between the systems of which they are composed.

Accounts of 'regime' shift or 'phases' in infrastructural development highlight important dynamics in infrastructural-institutional change. However, such infrastructural histories are mostly analysed in isolation, with interactions between infrastructures only rarely considered. Frantzeskaki and Loorbach's (2010) study is a notable exception in that these authors are explicitly interested in the 'interplay' between infrastructures including modes of competition, interdependence and joint use, as mediated by the different forms of 'flow' that infrastructures enable (this they describe as architecture). The suggestion that 'interplays are the mechanisms that underlie immanent infrasystem dynamics' (page 1294) is intriguing, useful and deserving of further development.

Frantzeskai and Loorbach introduce the notion of interplay in an attempt to explain how 'infrasystems' (as defined entities) respond to external changes, how they function as enablers or barriers to system transition, and how to design and plan changes therein. As elsewhere, the reciprocal interactions between infrastructures and the practices they enable receive scant attention. Instead, the tendency, which can also be observed in recent research on sociotechnical transitions (e.g. Schot et al., 2016), is to refer to 'users' whose responses shape pathways of innovation, rather than to analyse collective transformations in social practices and how these co-evolve with changes in intersecting infrastructures.

2.2. Conceptualising intersections

A more relational understanding of infrastructure, as developed by Star and Ruhleder (1996) 20 years ago, provides the basis for a very different interpretation of how infrastructures and societal transformations develop together. Star and Ruhleder suggested that, rather than being a substrate upon which something operates, infrastructures are best conceptualised as processes that become in relation to organised practices; infrastructures do not exist stripped of use, but are relational properties that shape and are shaped by practices; they are learnt, embody standards and tend to extend rather than to grow *de novo*. There are no absolute boundaries or *a priori* definitions to infrastructures. Taking a similar approach, Shove (2017) suggests that infrastructures are material arrangements that, in use, have an 'infrastructural' relation to the practices they enable. They are not used up (like resources), nor are they interacted with directly like tools, devices and appliances.

Understood thus, the range of technologies, systems and networks that stand in an 'infrastructural' relation to different practices varies from case to case, and changes over time. Moreover, if practices are intersecting and interwoven – for instance, using a car to drive to a large supermarket to shop for food stored at home in fridges-freezers – then the infrastructures supporting these practices are not fully separate and independent. Individuating such infrastructures and analysing them in isolation from others means that many causes of change and dynamics may remain undetected. Focusing on intersections between infrastructures and associated practices offers different perspectives on change compared with those associated with the dominant 'evolutionary' model outlined above. As the empirical cases discussed below suggest, intersecting infrastructures are always in flux, often in ways that are not anticipated or controlled. They have complex, collective

and emergent qualities irreducible to the features of one 'infrastructure' alone.

None of this denies the existence of patterns or orders. Past and present infrastructural intersections condition future conjunctions, and different types of intersection exist: variously more competitive, collaborative, or merely co-existing. However, too quickly deploying fixed categories and generic models can easily replicate narratives dominated by processes such as zero-sum competition, generic phases, path dependence, and singular trajectories. Attending to intersections forces researchers to consider and conceptualise forms of 'co-evolution' not between one infrastructure and its 'societal context' (societal function or need) but between co-existing and sequentially ordered forms of infrastructural arrangements with the no less multiple and dynamic complexes of practice to which they relate and through which they are defined.

2.3. Cases of intersection

Situated accounts of the role of infrastructures in societal transformations do not only offer specificity and eschew generalisation. They seek to make broader claims that are potentially relevant to unstudied situations, places and times. They are thus analyses of cases rather than case-studies. Berlant (2007) similarly distinguishes between a case-study as an exemplar or explanation about a person, thing, or event - frequently as a closed object of knowledge - and the case as a "problem-event" (Berlant, 2007: 663) that "can incite an opening, an altered way of feeling things out, of falling out of line" (page 666). Cases enable thinking – and feeling – in new ways that are grounded in particularity but extend to situations and contexts elsewhere. As a result, the relation between the general and the particular is more complex than when generic categories and models are mobilised to make sense of the complexity and messiness of the real world.

Whilst this justifies a focus on cases, there are nonetheless many situations that could be considered when trying to conceptualise the role of infrastructures in societal transformations. The criteria for selecting relevant instances are not clear and there are many reasons why cases and analytic frames might generate new modes of thinking. In this paper we take a pragmatic approach, focusing on aspects of our own and our colleagues' research that made us think about how infrastructures intersect with each other and associated practices and change, and that made us do so in ways that do not fit with established 'developmental' accounts or with evolutionary or 'multi-level' models of change. The cases we consider differ markedly in terms of spatial and temporal scale, and the actors, sites and materialities involved, but as detailed below, they help identify four of many potential forms of intersection.

3. Analysing intersecting infrastructures

3.1. Co-constitution between infrastructures: cycling and driving in Copenhagen

The story of how automobility (Urry, 2004) came to supplant other transport systems is often taken as an exemplary narrative of transition (Geels, 2005b). This is much more than a tale of purely 'technological substitution', and there is no question about the importance of intermediate stages and systems (e.g. electric trams and bicycles). Nonetheless, the rise of automobility is essentially conceptualised as an outcome of competition between infrastructures *qua* systems, and from which a new incumbent regime emerges.[1] One can read the urban

dominance of the car like this, but the history of 'cycling cities' raises questions of this model.

In 2014, 30% of trips within Copenhagen were by bicycle. Here cycling operates as a normal mode of transport for the whole variety of trip purposes and is not culturally marked as different (Aldred, 2012). Copenhagen also has a network of 350 km of cycle paths and lanes, separated from other traffic to various degrees. This represents a physical infrastructure of velomobility (Watson, 2013) which exists in parallel to that of automobility. Cycling and driving both figure as sociotechnical systems comprising practices, materials, norms, laws, and representative and lobbying institutions, so how might we understand their interaction: as co-evolution, co-existence or competition?

In Europe and the US the pattern is one in which cycling has been steadily displaced by public transport and more crucially cars, from the post-war period on (Manderscheid, 2013). Whilst many cyclists rely on roads, and so-called 'cycling cities' exist (e.g. Cambridge in the UK) the overall trend is in favour of the car. Transport studies have sometimes related this to discourses of modernism, and to methods of infrastructural investment, modelling and strategies of 'predict and provide' that have co-constructed the reality they seek to describe and to which they respond (Vigar, 2013). The 'mobilities turn' (Faulconbridge and Hui, 2016) has reoriented cultural and political analyses of mobility systems, but sometimes retains this view of transport modes, for example, treating 'city space' as a shared infrastructural setting (Freudendal-Pedersen, 2013). This imagines rival mobility systems developing through a 'zero sum' competition for urban space, for instance as reflected in Gössling's (2013) account of Copenhagen's eventual "re-distribution of urban space in favour of the bicycle".

There are, however, other ways of conceptualising the co-existence of parallel and interpenetrating systems of cycling and driving. For example, cycle paths have been viewed by Oldenziel and De la Bruhèze (2011) not as a fixed infrastructure with an also fixed relation to the car, but as a 'malleable' technology serving different groups and purposes in different periods. As these authors explain, cycle paths have been variously adopted and created for the comfort of cyclists (1880–1920); functioned as a disciplinary tool of planners to keep cyclists in place (1920–50); removed in the name of progress, (1950–75); and since then, under the influence of cyclists' grass-root organizations, promoted as a safe and sustainable solution to urban traffic problems (Emanuel, 2016).

In each case, the cycle paths and the practices they sustain are co-constituted with, and in relation to, other transport infrastructures and practices. In Emanuel's (2012, p.48) historical account of Copenhagen, cyclists laid claim to the edge of the road, a space that was until then the preserve of horses and their riders. Conflict between cyclists and horse riders sparked the formation of a Bicycle Path Association in 1897, and marked the start of a political battle in which bicycles were framed as a utilitarian mode of transport in comparison to 'elite' competitors: horses, then trams and cars. Representatives of cyclists, lobbying groups and political supporters in local government have since been involved in actively developing a distinctive cycle infrastructure. Meanwhile, institutional practices such as traffic monitoring also played a role; traffic counts in 1906 established that bicycles outnumbered horses 200:1, which transformed institutional understandings of road space. The nascent 'cycle' infrastructure was a sociotechnical achievement of intersections, as stretches of paths ran alongside, were separated from, and/or combined with other traffic through the materials and norms of signs, kerbs, and hand signals (Vreugdenhil and Williams, 2013). Cycling and institutional practices constituted, and were constituted by, (emergent) infrastructures and by their relation to other modes of transport in urban space.

Local and contingent aspects of this history include Copenhagen's relative poverty meaning that cycling remained a dominant and increasing mode of travel through the Great Depression, far longer than in other European cities. In the post-war period, cyclists shared road-space with public transport more than with cars and as a practice and as a

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political force, cycling remained 'too big to fail', being symbiotically linked with the geographies of home, work and leisure, and with other transport systems. Cycling practices and the infrastructures that increasingly supported them transformed driving, public transport and walking. This was not a one-way process. The provision of new cycling infrastructure slowed as cycling eventually 'lost ground' to cars and buses and to a parallel and sometimes shared infrastructure of automobility. Even so, earlier patterns of radial urban development were made possible and sustained by cycling and cycle-paths together.

Emanuel's (2016) explanation of Copenhagen's cycling 'renaissance' from 1975 onwards is one in which latent physical infrastructure provides a basis for cycling practices, which were 're-activated' by socio-political changes in the surrounding 'sociotechnical regime'. These included poverty, again, and the oil crisis; the power of the environmental lobby and the radical left; the use of demonstrations; the municipal promotion of Car Free Days; traffic calming technologies; and even a 'national noise policy'. Membership of the main representative body for cyclists increased eightfold in 1975–1980, cementing the popular and political conditions for renewed investment in cycling infrastructure alongside spaces devoted to the car.

The infrastructure of velomobility supported cycling practices in parallel rather than in competition to those of driving, and politicized the seemingly apolitical building of the car city (Emanuel, 2012: 344), meaning that provision for cycling existed alongside a longstanding cycling culture as a component of a robust intersecting and coexisting mobility regime. In this way the ongoing interpenetration of cycling and driving infrastructure transformed both sets of practices. As re-presented here, these processes involved the co-constitution of both through forms of mutual adaptation and coexistence rather than zero-sum competition.

3.2. Threading through infrastructures: electric vehicle charging in Oxford

Change in infrastructures can unfold in ways other than through the sequence of distinct phases as characterised in the literature on societal transformations. Here we explore an alternative process which we refer to as 'threading through'. This entails adaptation of an existing infra-structure – the roads and streetscapes tailored to the needs of internal combustion engine vehicles (ICEVs) in the historic city of Oxford, UK – by the careful inserting of electric vehicle charging installations without pushing out other types of vehicle or road usage.

Oxford has an air pollution problem, transgressing legally binding limits for NO_x and PM_{10} on more days per year than is allowed under EU legislation. This problem, which is mainly due to motorised traffic, persists across the city (OCC, 2015) despite decade-long attempts to reduce such traffic. These include a very successful park and ride (P&R) system; a comprehensive radial bus network; a comparatively good cycling infrastructure in in the UK context (Parkhurst, 2004; Schwanen, 2015); and in 2014 the creation of a Low Emission Zone in the city centre, requiring buses entering the area to meet the Euro 5 standard for tailpipe emissions.

As part of its Air Quality Action Plan (OCC, 2013) and its ambition to enact a Zero Emission Zone for road transport from 2020 onwards, the city council is stimulating the uptake of electric vehicles (EVs) by developing a recharging infrastructure. Stakeholders have identified three notable challenges. Many households (28%) are in terraced properties, most with no access to off-street parking (OCC, 2016) and thus no guaranteed site for charging. In addition, outright competition between EV infrastructures and those for ICEVs, and for buses, cycling and walking is politically challenging and electorally risky. As in many UK cities, parking is a controversial topic in local politics. Finally, a facilitating and coordinating role for the public sector is required, because private firms have so far not been enthusiastic about creating an EV charging infrastructure and because there is no clearly preferred charging technology or method for integrating new systems with those already in place in public parking spaces and P&R sites.

Thus far, the city council has adopted a reflexive approach to the creation of an on-street EV charging infrastructure. In line with the transition management approach (Loorbach et al., 2015), social learning and experimentation play an important part. With financial support won competitively from the UK's Office for Low Emission Vehicles (OLEV), a project will trial innovative technologies for on-street EV charging. In the first instance, there will be multiple test installations for each of six new technologies – involving private households and a car-sharing scheme, spread across the city. The trial will last for a year or so, allowing the city council and its partners to learn about how the technologies perform, participants' charging practices and responses from neighbours. The trialled technologies differ on various dimensions, including the ease and cost of installation and the extent to which they integrate with pre-existing EV charging infrastructure. Some charging points come as stand-alone bollards, others are built into streetlamp posts, and one consists of a charger installed on a wall of a participant's property with a gully in the pavement for an extra-long charging cable.[2] These various options will be evaluated over the course of the trial and another 70 + installations of the most successful solutions will be built for households without off-street parking.

In this case, new techniques and procedures were adapted to existing streetscapes and designed to minimise competition with other forms of road usage. For instance, the installations have been sited carefully and the public consulted on each parking bay as part of the legally required traffic regulation order process. Objections by members of the public have sometimes led to the selection of alternative sites for which further consultation took place. The inclusion of installations where charging technology is integrated into lampposts is the result of a desire to minimise competition and disruption to pre-existing streets-capes. This is because multi-functional units offering lighting and charging services, and possibly also monitoring air pollution, parking availability and traffic levels with 'smart' sensors in the near future, prevent a cluttering of sidewalks with street furniture. This is advantageous from the perspective of particular practices and road users, including those packing/unloading cars, walking with prams, or the visually impaired. However, integrating charging technology into lampposts also creates complications (e.g. barriers and increased trip hazards) because the department responsible for lampposts is gradually relocating them away from the kerb-side of pavements, meaning that different parts of the council have to coordinate initiatives and strategies. The threading of EV charging infrastructure through existing yet dynamic streetscapes has consequently triggered changes to institutional routines in multiple and distributed sites.

These trial charging installations will generate continuous digital data to be monitored and evaluated for multiple purposes including providing information and evidence that legitimises the siting of installations and their puncturing and retrofitting of existing road infra-structures. 'Smart' digital systems – sensors, meters, cables, codes, practices, etc. – play a key role in the adaptation of existing infra-structures. Their 'smartness' simultaneously legitimises their introduction, and enables new installations to function as more than isolated pieces of equipment. The result is an infrastructure that is networked within itself, with pre-existing charging installations in public spaces in Oxford and beyond, *and* with an existing infrastructure of roads, homes and pavements.

3.3. Layering infrastructures: Manchester's Northern Quarter

Having considered forms of co-constituting through competition and the threading of one infrastructure through another, our third case addresses the historical sedimentation of multiple infrastructures in one particular urban area. A discussion of the development of Manchester's Northern Quarter allows us to show how infrastructures and the

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[2] See http://www.goultralowoxford.org/info/5/chargers

practices they underpin co-evolve, but in a non-linear and not necessarily path dependent manner. Importantly, what counts as obdurate or adaptable (Hommels, 2005) itself changes through shifting institutional and everyday practices.

The Northern Quarter is one of several 'areas' (e.g. the Gay Village, Spinningfields, Deansgate, the CBD or China Town) that have acquired a distinctive identity, partly as a result of deliberate planning, branding and marketing on the part of the city council. As represented today, the Northern Quarter accommodates "wholesale rag trade companies, creative businesses, niche and alternative retail, café bars, public houses, galleries, nightclubs and residential developments" (MCC, 2012, page 13), and has become known for its alternative nightlife and 'loft' apartment living.

The physical spaces and infrastructures that now make up the Northern Quarter were not designed or built with this mix of practices in mind. Many of the buildings were constructed in the late 18th and early 19th centuries, often with elongated second floor windows to provide light for cotton weaving and related activities. There have been subsequent waves of adaptation and modification. For example, more industrialised forms of spinning and weaving involved new machines and new patterns of employment, as well as infrastructures for power and lighting. Previously industrial properties have since been adapted for residential and commercial use, and the area has been marked by trends in retailing and city centre shopping. As in other major cities, small retailers and department stores have both been affected by the rise of out-of-town shopping centres developed from the early 1970s onwards. And at each point in this unfolding history, everyday practices and the infrastructures underpinning them have subtly or significantly reconfigured the Northern Quarter's material and spatial form.

This works at different scales. Individual buildings change hands and also change use. For example, what was the fish market is now the Manchester Crafts Centre. Similarly, 'Affleck's Palace', which used to be a major department store, has been divided into a combination of small shops and 81 loft apartments. These changes have not taken place in the abstract, or on a 'clean' canvas. Each shift builds on, and is in some measure shaped by what has happened before. Whilst the precise configuration of the Northern Quarter is unique, it is also defined by the transformation and circulation of practices and processes (from weaving to industrial production, to retailing) that exist beyond the city itself. At the same time, the Northern Quarter has been, and is still, made by the persistent durability of certain material features. In effect, aspects of the urban environment combine to form a kind of space-as-infrastructure that remains durable precisely because of its ability to adapt and change.

The shared 'structure' that is the Northern Quarter is, in turn, criss-crossed by networks of water, gas, electricity and telecommunications systems and related assemblages of pipes, wires, pumps, sub-stations and junction boxes. The routes traced by these systems, the dates when they were established, and the ways in which they have been maintained, augmented or abandoned are closely linked to the development, and also the decline of practices (and complexes of practices) enacted within the Northern Quarter. This is an ongoing process.

For example, since 2000 Manchester's electricity system has expanded. This has coincided with a rapid increase in the number of people living in the city centre, and especially in the Northern Quarter.[3] This is only part of the story. The need for more electricity is in part the result of a much longer-term pattern of industrial and commercial development, meaning that the Northern Quarter has a relatively limited infrastructure for gas. Looking ahead, recent investment in new substations changes the landscape of future possibility. New and different

developments become possible because of this investment in electrical power.

These observations point to what we might think of as the interweaving or recursive layering of obduracy and change. In effect, the apparent durability of repurposed buildings and augmented electricity infrastructures is indicative of processes of flux over the longer term. Exemplifying what Watson and Shove (forthcoming) refer to as forms of 'infrastructuration', the resources and infrastructures of the Northern Quarter shape and are also shaped by the practices that take place within that area. At various points in Manchester's history, some of these developments have been deliberately and consciously planned. Whether this is the case or not, interventions are always and unavoidably situated within, and part of the sedimentation of material arrangements, themselves linked to a persistently dynamic profile of activities and practices. In commenting on some of these shifts we have characterised the successive processes of layering and embedding through which urban spaces-as-infrastructures-for-practice are continually reconstituted.

3.4. Coexisting configurations: cooling food in Hanoi and Bangkok

Our fourth case concerns the uses of fridge-freezers in two rapidly urbanising settings: Hanoi, Vietnam and Bangkok in Thailand. At first sight, fridge-freezers are not infrastructures as classically understood, or even as characterised in the preceding cases. However, following Star and Ruhleder's (1996) argument that material arrangements, technologies and systems can stand in infrastructural relation to practices, it makes sense to see them in this role. Understood as devices that enable people to keep food cool, fridges have an 'infrastructural' (necessary background) role in relation to shopping and cooking practices, *and* in relation to systems of food provision, diet and (urban) modernisation. Defining infrastructures broadly enough to encompass both such roles allows us to identify some of the routes through which spatially extensive relations – here between food providers and consumers – are configured, and how these evolve.

Unlike the cases discussed above, state or city authorities are not directly involved, nor are the highly distributed infrastructures of refrigeration outcomes of deliberate planning and public investment. Numerous policies and programmes have an impact on how food supplies are organised, regulated and transported, but these tend to have effect 'behind the scenes'. For example, policies, including those relating to international trade, food standards and electricity supply, have a bearing on the availability of white goods, of certain foods, and of a suitably reliable source of power. In what follows we keep these features in view, but in the background of an analysis that focuses on intersections between kitchen infrastructures and household appliances, and on shifting understandings of diet and related practices of eating, cooking and sourcing food.

In less than two generations, fridge-freezers have become normal appliances in virtually all households in urban Bangkok and Hanoi. Our research (Rinkinen et al., 2017) showed that the 'need' for a fridge-freezer and the energy consumption associated with it was closely related to the dynamics of urbanisation and diversification in food provisioning, but not in any simple or predictable form. The 52 urban 'middle class' households we interviewed described a mixture of responses. For households that had adopted what was described as a 'Western' diet including dairy products and/or ready meals and processed food, fridge-freezers were integral to patterns of shopping and eating that involved supermarkets and convenience stores. For others, fridge-freezers were equally essential in circumventing just such arrangements. In these homes, it was important to have a fridge-freezer in order to maintain more 'traditional' systems of provisioning and avoid the health risks and loss of quality associated with mass produced food. Fridge-freezers were, for example, used to store provisions 'imported' from the countryside having been sourced from local producers or from family farms.

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[3] Manchester had the highest population growth of any UK urban centre between 2001 and 2011. Rae, A., 2013. English urban policy and the return to the city: A decade of growth, 2001–2011. Cities 32, 94–101, doi: https://doi.org/10.1016/j.cities.2013.03.012.

In Hanoi, especially, there were widespread concerns about food safety triggered by lengthening supply chains and growing distances between consumers and providers: trends that are themselves enabled by frozen and chilled food storage and transportation. Some households went to considerable lengths to bypass such regimes, using fridge-freezers to navigate *around* systems of provision that the fridge-freezer has enabled. Others described a mixed approach to provisioning, organised around subtle distinctions between different types of food and related interpretations of quality.

> Every weekend I go to the countryside to buy food and vegetables to store in the fridge. I only buy fruits and small things [cookies, candies, yoghurt and snacks, milk] in the minimarket nearby here but main things like meat, fish, I buy from the countryside
>
> (Hanoi, woman aged 30–40)

Such strategies depend on multiple co-existing systems of provision, not only of food but also of electricity and transportation. Without an unbroken cold-chain extending from producer to consumer it would be impossible to sustain the global spread of 'Western' foods, mass-produced ready-meals, supermarkets and distribution networks. But the mere existence of these intersecting arrangements (power, freezers, cold-chains) does not ensure their use. Alternatives and forms of 're-sistance' persist and perhaps thrive in reaction to apparently dominant conjunctions. Some of the 'elements' of these different but co-existing systems are shared: fridge-freezers are critical in both scenarios. Others are not, including the lengths of supply chains, shopping routines, the practicalities of storage, the specificities of diet and interpretations of quality.

Whilst fridge-freezers are increasingly common household appliances, this alone does not guarantee converging patterns of shopping, cooking or eating. Multiple histories, geographical contexts and specific trajectories of urban development were revealed in the contents of the fridge-freezers we studied, and in linked discourses of safety, quality and freshness. While certain practices (a convenience-based, Western diet) and systems of provision (cold-chains of food produced at a distance) were often anticipated and routinely enabled by the acquisition of a fridge-freezer, the collision between these 'new' practices and pre-existing systems of diet and food-sourcing resulted in new constellations of practices: co-enabled through devices-as-infrastructures.

The co-existence of rival, overlapping modes of frozen-food provisioning is evidently inconsistent with singular narratives of replacement, substitution or sociotechnical transition: instead there is evidence of co-constitutive tension between multiple arrangements. Over time certain intersections of provision, diet and infrastructure/technology *may* prevail, but not as a necessary outcome. As this case demonstrates, innovative technologies such as fridge-freezers, and related cold chains do not automatically substitute pre-existing infrastructural relations, but are instead 'cannibalised' by them in all sorts of unintended ways. In considering these processes it is especially important to appreciate the interwoven intersections of provision, diet and consumption, enacted and materialised via urban, and therefore stretched, distribution systems.

4. Discussion and conclusions

The strategy of analysing changing relations between infrastructures sketched here involves a small but significant shift of emphasis. Rather than characterising the trajectories of specific infrastructures or regimes as these develop over time, we have focused on forms of infrastructural intersection, illustrated with reference to a handful of examples: cycling and driving in Copenhagen, electric vehicle charging infrastructures in Oxford, the layering of infrastructures in Manchester, and the emergence of parallel systems of food provisioning in Hanoi and Bangkok.

Our selection of cases is limited and partial but in zooming in on these few instances we have been able to identify some of the ways in which infrastructures shape each other and together configure multiple pathways of change. The forms of intersection that we have discussed – co-constitution through competition; adaptation and threading through; historical layering; and coexisting configurations – are neither mutually exclusive nor the only modes that exist. They have certain distinctive characteristics with some entailing interaction between past and present arrangements and others revolving around forms of co-existence. Our aim, however, was not to provide a comprehensive typology of infrastructural intersections, or to predict either the emergence or consequences of one or more of these forms. In discussing the four cases we have sought to highlight the conceptual, methodological and political/practical implications of analysing, and perhaps shaping, the ways in which infrastructures interact.

Rather than examining how external context shapes a single infrastructure or system such as automobility or electricity provision, we have investigated some of the ways in which past and present infrastructures interact and shape each other. The conceptual and analytic focus is thus on connectivity itself rather than the systems that are thereby linked. In contrast to abstracted, generic 'phases' of development, the types of inter-relation discussed here have no obvious or necessary sequence. Historical layering (as in Manchester), does not necessarily pre-date forms of co-constitution through competition (as in Copenhagen), or vice versa. Instead, modes of interconnectivity appear to be more strongly related to considerations of scale, local history and politics.

While generic types of infrastructural interaction can be abstracted from the cases discussed, the specific combinations and conjunctions applying in any one empirical instance are unique to that situation. For example, the challenge of 'threading' an electric vehicle infrastructure through Oxford is, in detail, unique to that city and historical moment. Precisely what threading through involves in other cities and times will vary to some degree, due to infrastructural intersections that have gone before. Similarly, the positioning of fridge-freezers as critical nodes in mass-produced and localised forms of food provisioning cannot be assumed or anticipated in advance. This is because the relations between appliances and such systems are recursive, and the forms they take depend on a confluence of previous histories and practices, including traditions of shopping, cooking and eating.

Instead of sidestepping the historical, situated and multiple character of the processes involved and the different scales across which they play out, the challenge is to develop methods of conceptualising infrastructural intersections within and as part of this contingent flux. At a minimum, this calls for greater analysis and understanding of how *systems* co-exist and mutually adapt. This is particularly salient if infrastructures are not merely viewed as material and institutional forms, but as arrangements that are embedded within and constitutive of what people do. Following this line of argument, an interest in how infrastructures shape each other, and the practices they enable, opens up a research agenda organised around themes of multiplicity, scale and indeterminacy. Taking these themes to heart complicates essentially linear accounts of innovation, transition and sociotechnical regime change, and generates new theoretical and methodological challenges.

The cases we have worked with above make use of different empirical materials, methodologies, forms and 'scales' of analysis. This is a necessary feature in that multiple approaches are required to isolate and describe something as elusive as the routes and pathways through which infrastructures connect. In some instances, it makes sense to concentrate on instances of controversy and contest. For example, determining the road space allocated to cars and bikes – via white and yellow lines on the road – can indicate the changing, but always relative, status of driving and cycling. Such features signpost the ebb and flow of practices and act as traces of disputed and clearly political processes. Similarly, tiny details of lamppost re-design reveal methods of charging electric vehicles and show how the boundaries of private ownership, public space and infrastructural provision are being defined and negotiated in Oxford today. Very different techniques are needed to 'see' the cumulative status of domestic fridge-freezers as part of the

global frozen food system; to show how domestic infrastructures (power, food storage) are locked into (or enable escape from) dominant systems of provision (retailing, transport, manufacturing); and to reveal how these are entwined with urbanisation and the 'Westernisation' of diets in Asia and elsewhere.

Studying junctions and connections rather than actors, interests or technologies requires abstractions including holding certain features of the field provisionally stable, drawing boundaries, and leaving certain elements aside. It also requires plausible accounts of how observable traces – the marks on the road, the contents of the fridge freezer and so forth connect to 'larger' phenomena like global markets and national infrastructure plans. Moving between systems and scales is a pre-requisite for understanding how relations between infrastructures change and for catching sight of multiple systems in flux.

In coming to a conclusion, we argue that insights arising from analyses like cases like ours have implications for those seeking to promote or foster forms of innovation. Attempts to steer societal transformations in ways that engender lower carbon societies are associated with policies to decarbonise energy supply, reconfigure transport, and make buildings and manufacturing more efficient. Rather than focusing on systemic interconnections between infrastructures and practices there is a tendency to treat each system as if it exists independently and is subject to unique interests, levers and drivers of change. This makes some sense, politically, but our analysis of how infrastructures intersect and influence each other points to the need for systemic forms of intervention that directly address these co-constitutive processes.

So how, by whom, and at what scale are *infrastructural intersections* governed? Planners in Copenhagen, Oxford or Manchester have evidently sought to shape and modify infrastructure-practice trajectories. As represented here, previous histories, policies, and other co-existing systems and networks affect the processes they hope to influence. Since planners' actions are defined by these situations, following generic blueprints or transferable recipes for intervention is inherently problematic. In these and other contexts, attempts to design interventions to match stages of 'innovation stages' such as introduction, diffusion, and scaling up make little sense. Instead, effective intervention depends on understanding and navigating through unique, situation-specific and shifting opportunities – defined by the infrastructures in question as well as their interconnections and interactions with other interests and actors, both living and dead. In Oxford the work of introducing EVs is substantially defined by the actions and ambitions of Victorian and early 20th century builders whose infrastructures still prefigure present possibilities. In Copenhagen, cycling and driving lobby groups have interacted repeatedly. However, the possibilities for action open to each have changed alongside and as part of a series of parallel material and political histories.

In writing about Manchester, Copenhagen and Oxford, we have considered how state and market actors help constitute and modify the overlapping infrastructures of which urban centres are formed. In each case, there have been deliberate plans, discussions, policies and investment decisions. Working out 'who' is involved in shaping present and future systems of food provisioning is a much more complicated and perhaps hopeless task: there is no identifiable policy that has somehow 'led' to the emergence of a global frozen food system. Instead, such developments incorporate multiple, otherwise disconnected interventions, including national foreign trade policies; urban planning traditions; trends in the development of out-of-town supermarkets, and national and international policies regulating food safety and hygiene. There are of course corporate interests, along with market traders, family farms, and generations of people with different tastes, ideas and habits of shopping, cooking and eating. To varying degrees, all contribute to the 'governance' of frozen food.

This does not deny the potential for deliberate, purposeful intervention. But recognising that practices, and in particular, infrastructure-practice relations, are 'made' and transformed on an ongoing

basis, and that this 'making' depends as much on those who 'do' – that is, who cycle or drive; or who cook and freeze – as it does on road builders, local authorities, regulators or appliance manufacturers, changes how intervention is understood. One implication is that would-be interveners need to adopt a stance of permanently reflexive governance (Voss and Bornemann, 2011). Beyond recognising that many others are involved, this depends on constant monitoring and adaptation in ways that are sensitive to local politics and histories: interventions such as Oxford's EV scheme represent involvements in a stream of ongoing intersections across infrastructures and associated practices characterised by conflicts and synergies. Interventions happen not on a 'blank' slate, but as part of these multiple, intersecting trends and currents.

In conclusion, attending to infrastructural intersections challenges 'mainstream' accounts of staged societal transformation, with specific forms of governance and intervention associated with each phase. Instead, our approach highlights the extent to which infrastructures and practices intersect in ways that are shaped by their combined and separate histories. These intersections have consequences for future intervention, for what policy makers and others can do, and for how their actions (past and present) affect social, material and political arrangements, *and* for how these interact, now and in years to come.

Declarations

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