Original Research Article

BIG DATA & SOCIETY

Big Data & Society
July–December 2017: 1–16

DOI: 10.1177/2053951717742418
journals.sagepub.com/home/bds
SAGE

Algorhythmic governance: Regulating the 'heartbeat' of a city using the Internet of Things

Claudio Coletta and Rob Kitchin

Abstract

To date, research examining the socio-spatial effects of smart city technologies have charted how they are reconfiguring the production of space, spatiality and mobility, and how urban space is governed, but have paid little attention to how the temporality of cities is being reshaped by systems and infrastructure that capture, process and act on real-time data. In this article, we map out the ways in which city-scale Internet of Things infrastructures, and their associated networks of sensors, meters, transponders, actuators and algorithms, are used to measure, monitor and regulate the polymorphic temporal rhythms of urban life. Drawing on Lefebvre, and subsequent research, we employ rhythmanalysis in conjunction with Miyazaki's notion of 'algorhythm' and nascent work on algorithmic governance, to develop a concept of 'algorhythmic governance'. We then use this framing to make sense of two empirical case studies: a traffic management system and sound monitoring and modelling. Our analysis reveals: (1) how smart city technologies computationally perform rhythmanalysis and undertake *rhythm-making* that intervenes in space-time processes; (2) distinct forms of algorhythmic governance, varying on the basis of adaptiveness, immediacy of action, and whether humans are in-, on-, or, off-the-loop; (3) and a number of factors that shape how algorhythmic governance works in practice.

Keywords

Algorhythm, algorithmic governance, rhythmanalysis, Internet of Things, smart cities, time geography

This article is a part of special theme on Algorithms in Culture. To see a full list of all articles in this special theme, please click here: http://journals.sagepub.com/page/bds/collections/algorithms-in-culture.

> Can I understand the heartbeat of a city? That is really what it is. Whether it comes down to the smart lighting or some app that tells me where I can park or where I can't park, all of that stuff, rail, transport, any of that information that I have just got at the touch of a button... So when I see a smart city it is basically understanding the heartbeat of the city, being informed about it; that if there is any issues with it that it is quite easy to find where those issues are. (Start-up entrepreneur #1)

Introduction

Since the 1950s, with the introduction of Supervisory Control and Data Acquisition (SCADA) systems, technology has been utilized to manage and control urban systems in *real-time*, especially with respect to transportation, utilities and security, and to mediate the rhythms of city life. In recent years, such dynamic regulation and mediation has been widened and deepened with the rollout of ubiquitous and pervasive computing wherein computation is built into the fabric of urban infrastructure and is accessible from any location and on the move. As a consequence, a range of studies have noted how the deployment of smart city technologies is reconfiguring the production of space, spatiality and

NIRSA, National University of Ireland, Ireland

Corresponding author:
Claudio Coletta, Maynooth University, Iontas Building, W23 F2H6 – Maynooth, Ireland.
Email: claudio.coletta@mu.ie

mobility, and how urban space is governed (e.g., Crang and Graham, 2007; Gordon and de Souza e Silva, 2011; Kitchin and Dodge, 2011; Thrift and French, 2002). However, while some research has considered the effects of information and communication technologies (ICTs) on time and space – e.g., creating time–space compression, convergence and distanciation and altering socio-temporal relations (Castells, 1996), scant attention has been paid to how the temporality of cities is being reshaped by city systems that capture, process and act on real-time data (cf. Kitchin, 2014; Townsend, 2000; Willis, 2016). Moreover, time geography has little considered the role of code and new forms of urban Big Data in reshaping the temporality of urban processes, systems and life (c.f. Crang et al., 2007; Schwanen, 2007).

Smart city technologies – such as city operating systems, urban control rooms, smart grids, sensor networks, smart parking, smart lighting, city dashboards and real-time information apps – have a number of transformative temporal effects (such as altering temporal relations with respect to flexibility, nimbleness, pace, stasis/inertia, prioritization, distanciation, tracking trends, forecasting, nowcasting, scheduling, anticipation, and short-term/long-term planning), and are open to framing and analysis through different space/time perspectives – e.g., time geography (Hagerstrand, 1970), space-time (Massey, 1992), rhythmanalysis (Lefebvre, 2004[1992]) and timespace (May and Thrift, 2001). In this article, we focus attention on how systems that utilize or form part of the Internet of Things, and their associated networks of sensors, meters, transponders, actuators and algorithms, are being used to measure and regulate the concatenated rhythms of the city. Drawing on Lefebvre (2004[1992]), and subsequent research, we employ rhythmanalysis in conjunction with Miyazaki's (2012, 2013a, 2013b) notion of 'algorhythm' and nascent work on algorithmic governance, to develop a concept of 'algorhythmic governance' – the way in which code and Big Data are used to intervene and regulate the polymorphic temporal rhythms of urban life.

To illustrate our argument, we detail two brief case studies. First, traffic management and the on-going work within a traffic control centre to gather real-time data on traffic conditions and the rhythms of traffic flow in order to dynamically manage a complex network in flux and to keep traffic moving. Here, our analysis utilizes ethnographic fieldwork in which one of the authors spent time in a traffic control room observing the work of the intelligent transport system and its controllers and managers, and on a set of related interviews. Second, real-time sound monitoring utilizing a network of sensors, wherein the data are fed back to city managers and analyzed, and shared with the public through a city dashboard. Here, our analysis draws on a set of interviews with system developers and those that analyze, utilize and share the data. In both cases, the interviews are drawn from a larger set of 77 conducted with city workers and stakeholders involved in smart city initiatives in Dublin, Ireland. These two case studies illustrate two different types of algorhythmic governance: the first more interventionist, adaptive and direct, wherein the on-going management of a city system is over-determined by code; the second more contextual or performance management orientated, wherein the rhythms are measured, monitored, recorded and modelled, with interventions more periodic and indirect.

Rhythmanalysis and the (smart) city

Rhythmanalysis (2004[1992]) was the fourth and final instalment in Henri Lefebvre's multi-volume work, 'Critique of Everyday Life' which was published between 1947 and 1992. The book, published posthumously, and was a key contribution, along with *The Production of Space* (Lefebvre, 1991[1974]), to his 'attempt to get us both to think space and time *differently*, and to think them *together*' (Elden, 2004: ix, original emphasis). Lefebvre's 2004[1992]: 15) core argument is that '[e]verywhere where there is interaction between a place, a time and an expenditure of energy, there is rhythm', meaning that everyday life unfolds within 'patterns of flow that possess particular rhythmic qualities' which produce a sense of continuity and stability, or disjuncture (Edensor, 2010a: 3). Peoples' lives therefore take place within a set of oscillating space-times, some of which are encountered regularly, some more periodically; or to put it another way: 'what we live are rhythms' (Lefebvre, 1991[1974]: 206).

Lefebvre identifies two main types of rhythms, linear and cyclical repetition (Lefebvre, 2004[1992]: 8). As he notes, people are often encountering and co-producing several of rhythms simultaneously such that cities host a series of 'intersecting rhythms, including the polyrhythmic [multiple], eurhythmic [harmonious and stable], isorhythmic [equal and in sync] and even arrhythmic [out of sync and disruptive] measures as well as secret, public, internal and external beats that comprise the symphonic everyday' (Conlon, 2010: 72–73). In other words, cities consist of a 'multiplicity of temporalities, some long run, some short term, some frequent, some rare, some collective, some personal, some large-scale, some hardly noticed' (Crang, 2001: 190). These rhythms 'may clash or harmonize, producing reliable moments of regularity or less consistent variance' (Edensor and Holloway, 2008: 484). Thought of in this way, places – the conjoining of space and time – unfold as events, wherein multiple constellations of trajectories, processes and temporalities 'collide, synchronise and interweave' (Jiron, 2010: 131).

A key aspect of how rhythms unfold, are maintained and are discernible from noise, and also mutate, is repetition. Basic elements of a rhythm are repeated to create an order, a refrain. In Deleuze and Guattari's term (1987[1980]), a refrain consists of 'any aggregate of matters of expression that draws a territory and develops into territorial motifs and landscapes'. Refrain is rhythm that becomes expressive, and it is this refrain, individually and collectively reproduced, that produces ordered space-time (Spinney, 2010). As Brown and Capdevila (1999: 36–37, cited in May and Thrift, 2001) explain, '[a] refrain… is a rhythmic series… that creates, by its very repetition, a sense of the familiar, a sense of place.' They elaborate that:

> [a]s the territory becomes secured, so the refrain is 'picked up' or reiterated by others who come to occupy the same space, much like the bird songs or, they argue, cultural myths. Each time the refrain is picked up, it is articulated anew, yet it still remains recognisably the same repetitive series. (pp. 36–37)

Refrains enact what Deleuze and Guattari call 'productive repetition' (1987[1980]: 314): not simply the return of the identical ('the reproductive meter'), but the creation of difference. Here, '[t]ime is not an a priori form; rather, the refrain is the a priori form of time, which in each case fabricates different times' (p. 348). As Lefebvre notes, 'there is no identical absolute repetition, indefinitely. As such, while a system might work to try and maintain a refrain, to maintain a eurhythmic state, it is always unfolding in a slightly imperfect form, or it might be 'punctured, disrupted or curtailed by moments and periods of arrhythmia' and dissolve into noise (Edensor and Holloway, 2008: 485). Rhythms then are not already given, but emerge as beats in the superposition of multiple and heterogeneous temporal flows and routines; these beats, in turn, perform differences and require new attunements to bring them into order.

As Elden (2004) details, Lefebvre uses rhythm not just as an object of study, but also as a mode of analysis. Rhythmanalysis thus seeks to unpack the ways in which time, space and lived experience are folded into, conditioned by, and produced through various rhythms (Edensor, 2010a; Lefebvre, 2004; May and Thrift, 2001). Lefebvre is fairly vague on what rhythmanalysis looks like in practice, and those that have sought to deploy his ideas empirically have used a range of different methods (see Edensor, 2010b for examples). As noted, our approach has been to use a combination ethnography and interviews that have sought to understand how city managers and the software-enabled systems they use measure and manage the polyrhythmic city. Lefebvre (2004[1992]: 8) places particular focus on measure contending that while 'rhythm seems natural, spontaneous, with no law other than its unfurling.… Rhythm, always particular, (music, poetry, dance, gymnastics, work, etc.) always implies a measure. Everywhere where there is rhythm, there is measure, which is to say law, calculated and expected obligation, a project.'

The relationship between calculation and management in producing urban rhythms is the empirical focus of this article, with particular attention paid to how new smart city technologies are being used to mediate and regulate the multiple rhythms of cities; to conduct a rhythmanalysis of the measure, work and effects of Internet of Things infrastructures that seek to limit arrhythmia and produce eurhythmic systems than maintain refrain. As noted by a number of commentators, the monitoring, planning and coordination of urban systems and services are increasingly being mediated by software-enabled technologies processing real-time data (Kitchin and Dodge, 2011; Luque-Ayala and Marvin, 2016; Townsend, 2013). Here, governance is delegated to digital infrastructures (DeNardis and Musiani, 2016) and enacted through forms of 'automated management' (Dodge and Kitchin, 2007), wherein human and social action are increasingly mediated by black-boxed algorithms that are inaccessible to public scrutiny (Gillespie, 2014; Janssen and Kuk, 2016; Pasquale, 2015). As a consequence, software is re-framing time and temporality (Hassan and Purser, 2007), and the space-times of cities are undergoing significant change.

Although Lefebvre in his later years showed strong interest in ICTs and their role in the capitalist mode of production (Lefebvre, 1996), it is only in the last few years that rhythmanalysis has been deployed for studying the work of algorithms, for example in environmental (Palmer and Jones, 2014), energy (Walker, 2014) and financial processes (Borch et al., 2015). However, as noted by Borch et al. (2015) in their account of high frequency trading in financial markets, 'the bodily focus of Lefebvre's project makes it unsuitable for fully grasping the development toward algorithmic trading' (p. 1084), and by extension sensing infrastructures. This is because, they explain, high-frequency trading algorithms are 'designed to detect and respond to market rhythms' and the 'rhythmic interactions *among* algorithms take place in ways that are not bodily founded or related' (p. 1084: original emphasis). This is not to say that the rhythm of human bodies is not attuned to trading markets, but algorithms are largely working in ways independent of body rhythms. A further shortcoming in Lefebvre's rhythmanalysis – as noted by Kofman and Lebas (1996: 48) – is the lack of 'a sustained analysis of the production of time, although his analysis... certainly yield significant insights on presence and absence, multiple temporalities and the interplay of time and space'. If measure and calculations are consitituve aspects of rhythms and there is 'no rhythm without repetition in time and in space', and if repetition entails difference (Lefebvre 2004[1992]: 6), then a focus on algorithms suggests to us a need to rethink measures, linearity and cycles as effects of rhythm-making processes. Accordingly, the multiple and entangled character of rhythms requires the interaction between human bodies and everyday life on the one hand and code and organizational processes on the other to be accommodated, to which we now turn.

Algorithms, governance and rhythms

Fundamentally, software is composed of algorithms – 'sets of defined steps structured to process instructions/ data to produce an output' (Kitchin, 2017: 14). Gillespie (2014) thus notes that all digital technologies are 'algorithm machines', able to tackle a diverse set of tasks automatically, quickly, efficiently, effectively, and inscrutably. Given these qualities, many aspects of everyday life are increasingly being mediated, augmented, produced and regulated by digital devices and networked systems. As noted, this includes a diverse set of city systems and infrastructure, where algorithms are deployed to 'search, collate, sort, categorise, group, match, analyse, profile, model, simulate, visualise and regulate people, processes and places' (Kitchin, 2017: 18). In turn, this has enabled new forms of algorithmic governance to be enacted, whereby 'algorithm machines' are used to actively measure, monitor, manage and control populations and the space-times of cities.

In recent years there has been an increased focus on the nature, working and effects of algorithmic governance across a range of domains (e.g., finance, health, education, work). This has included research that has examined and theorised how various forms of algorithmic governance is reshaping the management, control and governmentality of space and mobility. For example, Graham (2005) detailed processes of algorithmic spatial sorting in which people are classified with respect to place and differentially treated, and in later work (2011) set out how cities were increasingly under siege through various forms of automated surveillance and regulation (e.g., CCTV, transactions, satellites, drones, etc.). Amoore (2006, 2013) examined the use of algorithmic regulation in border security, and in the calculation and management of socio-spatial risks. Kitchin and Dodge (2011) documented the various ways in which people, objects, territories and transactions are algorithmically tracked and acted upon, and detailed forms of automated management in which 'algorithm machines' are ceded the power to act in automatic, autonomous and automated ways. More recently, Klauser et al. (2014) have examined the changing nature of governmentality enacted through the use of smart metering and smart grids and Luque-Ayala and Marvin (2016) have documented how new centralized urban control rooms enact new forms of real-time governmentality; Leszczynski (2015) has explored anxieties of surveillance and control in an age of spatial Big Data practices and dataveillance; Kitchin et al. (2015) have detailed how new streams of urban Big Data and city dashboards are enabling forms of new managerialism, performance management and technocratic modes of governance; and Kitchin (2016) has examined the ethics of governing through smart city technologies and issues of profiling, discrimination, bias, due process, accountability.

In general, these studies have little considered the ways in which algorithms are temporal in nature, and at best only implicitly note the temporal as well as spatial work of algorithmic governance and how they mediate the rhythms of urban life. Here, we want to consider the temporal dimensions of algorithms and their work, reframing them as algorhythms that produce modes of algorhythmic governance; that is, structured forms of knowledge designed to create euryhtmia – a familiar, desired refrain.

Miyazaki (2012, 2013a, 2013b) introduced the concept of an 'algorhythm', blending together the notion of an algorithm's sequence of step-by-step instructions with rhythm's time-based order of movement to consider how computation 'manifests itself as an epistemic model of a machine that makes time itself logically controllable and, while operating, produces measurable time effects and rhythms' (2012: 5). Miyazaki (2013b: 520) contends '[a]lgorhythms are vibrational, pulsed and rhythmized signals constituted both by transductions of physical fluctuations of energy and their oscillations as well as by abstract and logical structures of mathematic calculations.' He shows how the micro-temporal 'agencement' of such algorhythms – namely the technical and social linkages creating the condition for actions (Hardie and MacKenzie, 2007) – produce and mediate everyday life, but can also generate major failures in networks and services, such as in the cases of the AT&T telephone network crash in 1990 or the Flash Crash of the New York Stock Exchange in 2010. Likewise, Introna (2016: 21, original emphasis) argues that algorithms have a temporal flow consisting of 'a continuous string or stream of interpenetrating – prior and subsequent – actions that compare, swap, sort, allocate, administer, and so forth' where '[e]very particular "doing" happening in the present already assumes some *inheritance* from antecedent "prior-to" actions, and it already anticipates, or *imparts* to, the subsequent "in-order-to" actions'.

While Introna (2016) emphasizes the polyrhythmic concatenation of multiple computational systems, wherein a number of algorhythms and temporal flows intersect and interact, we are more interested in how sequences and concatenations are *repeated*. Likewise, while Miyazaki is concerned with conducting media archaeologies of algorhythms and computing infrastructures, we focus on how the rhythms of urban systems and the space-time unfolding of place are algorhythmically mediated; how forms of algorhythmic governance are being produced that explicitly measure and modulate urban rhythms – in our case the flow of traffic and the fluctuations of noise. The challenge here is to connect what Miyazaki (2012: 7) calls 'the time-boundedness of computational culture' to the time-boundedness of governance cultures in order to account for the interplay, interference and synchronization of the multiple refrains of smart urbanism. As Mackenzie (2005: 91) puts it, '[t]he problem, therefore, is to find ways of articulating the uneven, mixed timings that emerge within real networks of inter-operating systems,' acknowledging that algorithms are an essential part of a larger framework, entangled and displaced in a wide network of epistemic practices, organizations and infrastructures (Dourish, 2016). Our approach is thus to deploy a form of rhythmanalysis at the level of an assemblage of related governmental technologies – the control room, a sound network – rather than individual algorhythms; to examine how inter-related sets of digital technologies work together or in conflict, perform synchronization and interact through diverse calculations and repetitions. Thus conceived, algorhythmic governance can be considered as one of the multifarious forms of urban governmentality enacted by algorithms. As we detail elsewhere, urban informatics are shifting governmentality from disciplinary forms to those of social control; rather than governmentality molding subjects and restricting action within spatial enclosures, it seeks to modulate affects and channel action across space (Kitchin et al., 2018).

Algorhythmic governance in practice

Traffic management

The Dublin Traffic Management and Incident Centre (TMIC) provides a single, integrated, 24/7 control room to house the core traffic management systems for monitoring and controlling the road transportation network and traffic flow in the Greater Dublin Area, including dealing with major events and incidents. The TMIC is located on the top floor of the Wood Quay Building and access is restricted to selected personnel. The control room has nine main desks for operators, each provided with a computer, telephone, CCTV control and three displays (see Figure 1), that all face a large wall display with screens arranged in multiple sections that show live traffic conditions and allow controllers to share one of their screens with the room. One of the desks is reserved for the control room supervisor, one for a AA Roadwatch operator (who communicates traffic news to radio stations throughout the day), and three of the desks are reserved for the Gardaí (police service), Dublin Bus and ITS (Intelligent Transportation System) staff. Three smaller desks are located in the back left corner of the room and hosts Dublin City FM's live broadcast of traffic news and music between 7–10 a.m. and 4–7 p.m., Monday to Friday (staffed by a presenter, assistant and producer; http://www.dublincityfm.ie/). In addition to the main control room there is a smaller situation room with further screen and equipment to manage special events, and a small kitchen.

The TMIC is a busy, time-critical environment, with its own overlapping and intertwining everyday, work, machinic and algorithmic polyrhythms operating on different temporal cycles: the peaks of morning and evening rush-hour; people entering or leaving the room at breaks or as shifts change; the voice and music on the radio; the operators typing at keyboards and switching between cameras; and hurried conversations or jokes and the sharing of screens as a situation unfolds. At all times, real-time information is flowing into the centre from a fixed network of 380 CCTV cameras,

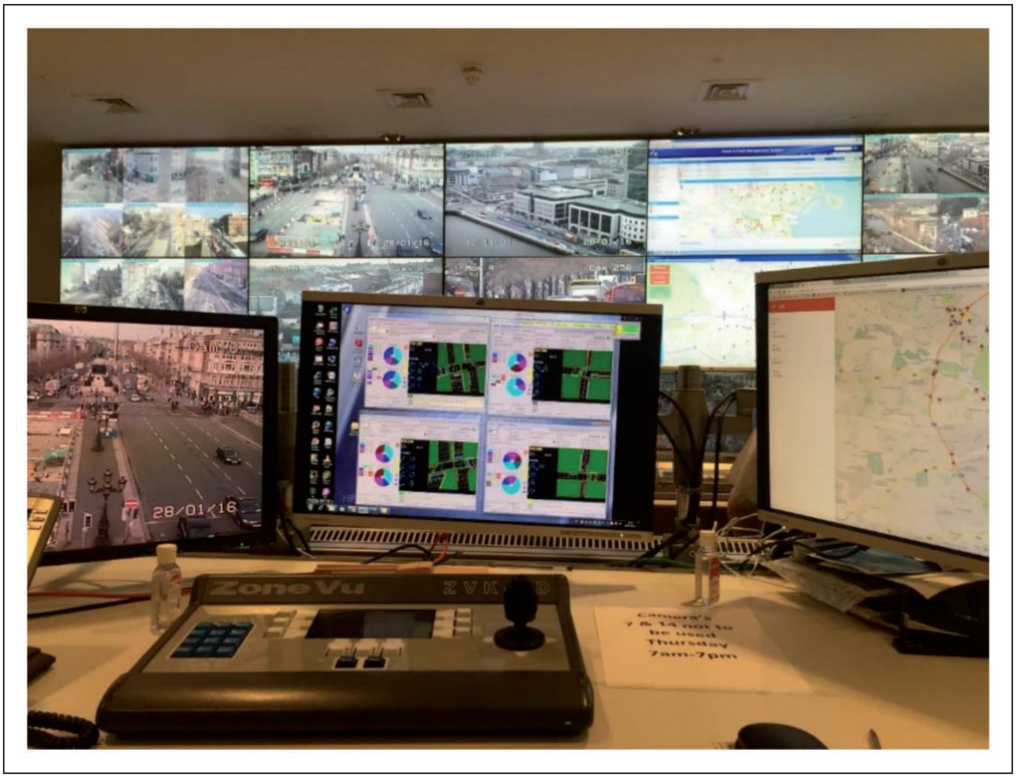


Figure 1. The view at a traffic controller's desk.

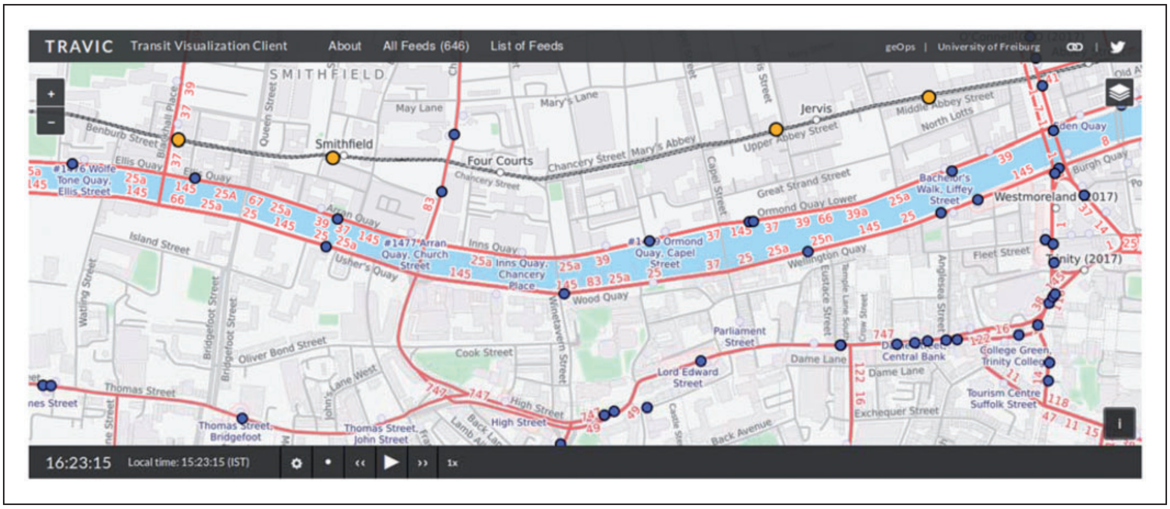


Figure 2. Real-time visualization of Dublin public transportation vehicles; yellow dots: Luas trams, blue dots: buses (source: Travic).

800 sensors (induction loops), a small number of Traffic Cams (traffic sensing cameras) used when induction loops are faulty or the road surface is not suitable for them, a mobile network of approximately 1,000 bus transponders (controllers can also directly contact drivers if needed; see Figure 2), phone calls and messages by the public to radio stations and the operators, and social media posts, which contingently and relationally shaping the core patterns of activity. At the centre of this activity is the adaptive traffic management

system, Sydney Coordinated Adaptive Traffic System (SCATS).

SCATS is an automated and adaptive system for managing the flow of traffic through a city. It synchronises traffic lights automatically, calculating the timing of signal cycles and phases at junctions depending on traffic conditions in order to ensure the optimal flow of vehicles and minimize congestion and manage incidents. In so doing, it dynamically manage the polyrhythms of road transportation and pedestrian crossings. A cycle is the wait time at a junction and is subdivided into phases for different directions and types (e.g., vehicles, cycles, pedestrians) of flow. It is adaptive in the sense that the system automatically adjusts the cycles and phases dependent on a set of programmed rules and the volume of traffic in previous cycles and phases. As McCann (2014: 8) details:

> 'SCATS has a hierarchical structure, featuring two distinct levels or layers of control: strategic and tactical. At the tactical level, control is undertaken by the local controller, allowing green phases to be terminated early and omitting phases for which there is no demand. Decisions are made based on information from vehicle detectors at the junction. At the strategic level, the regional computers use flow and occupancy data collected from vehicle detectors to give coordination between groups of junctions. Optimum cycle length, phase splits, and offsets are determined on an area basis, and not just for one junction.'

In effect, SCATS operates at three levels of control (McCann, 2014): at the level of the single intersection, a subsystem and a system. A subsystem is an amalgam of closely related junctions, including a 'critical' junction and adjacent minor junctions and pedestrian crossings. 'Within a subsystem, all junctions operate at the same cycle time and will have offset values designed to provide synchronisation between the junctions at all times of day' (McCann, 2014: 15). The system level seeks to provide coordination between subsystems by linking them together using external offsets.

Across the subsystems and system, the adjustment of time is based on the *degree of saturation* (DS), a traffic demand measure, and managed strategically at a regional computer. The DS algorithm measures how effectively the road is used and what should be the maximum flow allowed based on the number of vehicles flowing through a junction in a given time period. The DS indicates if the road usage is under or over-saturated, which is then used by SCATS to self-calibrate.[1]

As explained by the centre manager:

> The SCAT system is set up with the various different phases, the various different approaches it can run so it can run the main road, side road, pedestrian, right turns, whatever, so that is all set up by the staff here. That is programmed into the traffic controller. When the traffic controller gets switched on then there is an initial set of times, but once it gets that initial set of timings, SCATS itself will start to calibrate to the traffic flow. So it *self-calibrates* to the traffic flow. And then what it is looking to do is it is looking to equalize, to balance the competing demands at junctions. So that is the first thing it is trying to do. The second thing is, depending on where those junctions are, we may then decide they should be linked to each other to provide progressional flow from one to the other. So it has got to maintain coordination with its neighbors. [...] During the heavy, busy hours, you might have a lot of junctions along the road all linked to each other for cordination purposes, but as the traffic need dies down they could revert back to smaller and smaller clusters of traffic controllers who just respond more to their local needs, so they perform better just at their local needs. (Senior executive officer #1, Local Authority, our emphasis)

Calculations, calibrating processes and practices are at the core of the production of linear and cyclic rhythms: time is not given, but is built through the interaction of multiple adjustments which shape the measurement and practices of rhythms. Indeed, calibration as defined by the Oxford English Dictionary[2] refers both to an act of measurement ('to determine the correct value') and to an act of modification and adaptation ('to graduate objects for any irregularities'). Thus, the calibration takes into account the interactions within the TMIC as performed by the controllers as well as the flows of traffic and pedestrians, who through their movements and actions at a junction contribute to and are affected by the system's algorhythms. For example, by pressing a pedestrian crossing button at junction, people produce a temporary break in the traffic rhythm closing down the main phase in order to run the pedestrian phase. Similarly, the number of cars and the gaps between them detected by the induction loops communicates if a phase was too short or long and the next phase time is re-calculated automatically by the SCAT system. Public buses benefit from prioritisation, so as they approach a junction the phasing will alter to accommodate their passage, generating a further alteration of traffic rhythms that need to be managed by the

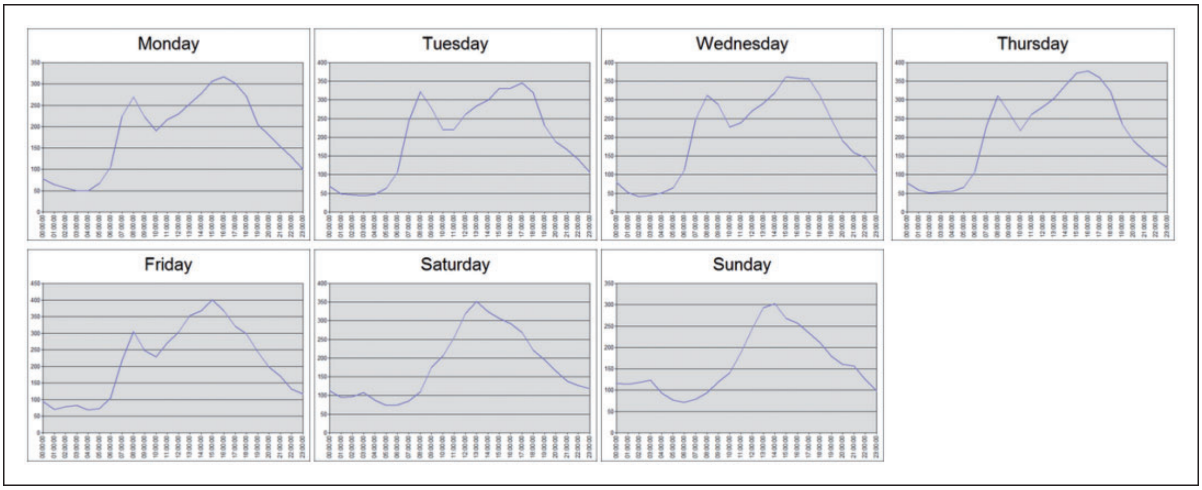


Figure 3. Four month average of traffic flow through a junction phase.

software, and which sometimes produces congestion in the other phases. Cycles are set to last a minimum of 40 seconds to a maximum 130 seconds, but in practice they rarely exceed 80 seconds or go below 60 seconds. This is based on the pragmatic evaluation that the waiting time for a pedestrian crossing above 80 seconds would be too long:

> ‘So then that means that throughout the day when it is not busy the cycle goes between 60 and 80 seconds which just means that if a person is waiting at the side of the road they are not waiting too long, or the people at the side roads are not waiting too long. Because if you have everything at 120 and all the additional [time] goes to the main road you could be sitting on the side road for maybe 80 seconds which is a very long time.’ (Senior execuive officer #2, Local Authority)

Calibration is strictly related to repetition: the repeated passage of cars at specific intervals of time produce a temporal pattern that SCATS uses to adjust the phases. The association of calibration and repetition through calculation produce the *refrain* of traffic management. Refrains enable data actionability and accountability, and are used by ITS staff to configure the setting of SCATS taking into account whether it is a weekday or weekend, as well as seasonal/daily rhythms and when schools are closed. Consequently, each phase of each junction has its own temporal rhythms which can be discerned over time. Figure 3 displays an average (over 4 months) flow of traffic through one junction phase over 24 hours for each day of the week, showing a morning and late afternoon/evening peaks for weekdays, but early afternoon peaks at the weekend.

On the management side, operators can intervene and override the original SCATS settings, as well as its present conditions. Figure 4 shows the SCATs interface as interacted with by a controller, with the right-hand part of the screen showing a junction and its phases, and the left hand part the length of time for each phase. Interventions are circumscribed by the configuration of the system by ITS staff, which in turn refer to the Traffic Signs Manual by the National Roads Authority,[3] which gives rules on the minimum and maximum times for phases. If, for example, operators try to go below the minimum safety times for green or red time on a different phase SCATS will automatically override the modification attempt with the original configuration:

> We have a number of rules and a number of different elements that you do, so you draw a diagram of what your phasing is going to be, you then define what signal groups can run at the same time as the other, you give basic timings, you give minimal times for your pedestrian crossings, you calculate what the critical collision point is, so what phases. How long the inter-green time has been the different phases and any other requirements that you want to have, i.e. if you want phases to be allowed to be controlled by different factors, so if you turn on switches or turn on different things, different things happen. (Senior executive officer #2, Local Authority)

As well as directly altering the phasing of junctions and the rhythms of traffic flow, much of the data utilised in the traffic control room is shared with the public via a number of channels, enabling people to see and

SCATS Access

Central Manager - CMS

User 67 - Level 6

01/11/2016 10:47:

(1) 197 - Bachelors Walk : Dublin (TCC) - CCITY

Cameras 6

197

Alarms DA SI CA NF

CCITY Subsystem 35

Degree of Saturation 100

SCATS 6

Split Plan 5

Masterlink

System Plan 5

Master Subsystem

Cycle Generator 99

Offset Plan 4

Offset 0, 0 B

Link Plan 4

Link none

Active Link none

Special Facilities Z3,6

Cycle Plan none

Cycle Length 116

Required Cycle Length 110

XSF

TCS 197

CCITY SS=35

5 PHASES

YEL B W2@11 MX@23 P^A@24

2016-01-05 For operation during luas Bridge works see notes -KH

On DCC Copper 172

Active Offset 0 B

Site Fallback 0

MSS

Masterlink

Region - CCITY - Version 6.9.2.19

User 67 - Level 6

01/11/2016 10:47:0

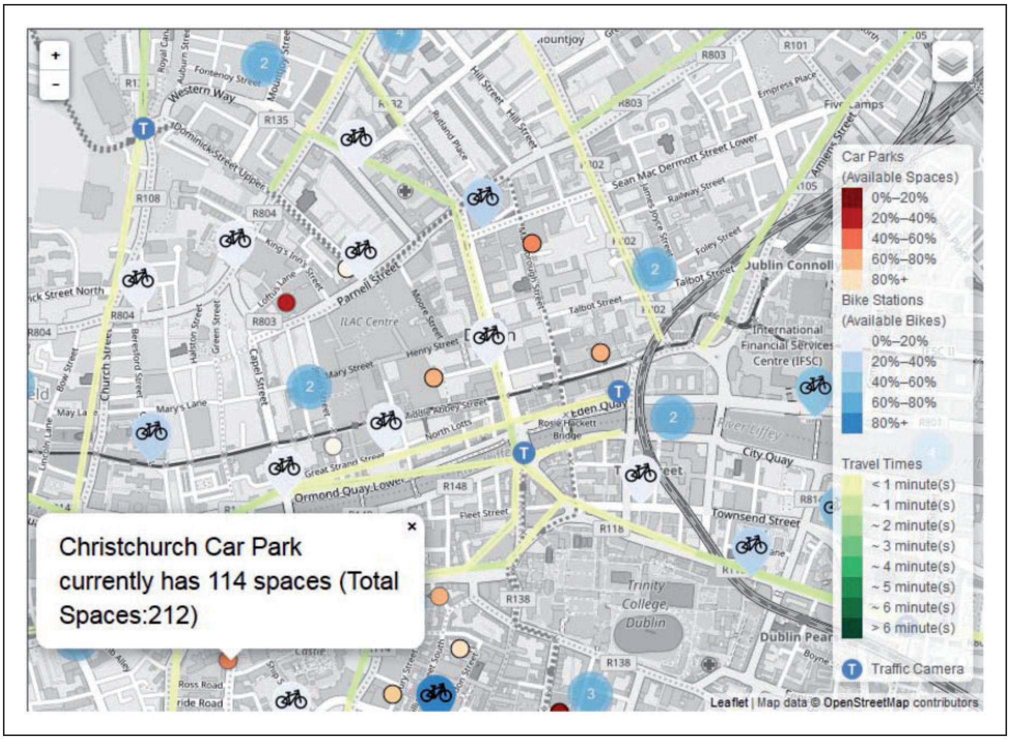
Figure 4. SCATS interface, the pie charts represent the cycles and each colored slice of the different phases and the proportional time allocation. SCATS: Sydney Coordinated Adaptive Traffic System.

interpret the data themselves and self-regulate their interactions with the traffic system and to manage time-based decisions for journey planning. For example, real-time information about the expected real-time of buses and Luas trams are shared via smartphone apps,[4] websites[5] and on-street signs (see Figure 5). The Dublin Dashboard[6] provides real-time information on the estimated travel time along road segments, the number of spaces in the car parks, the number of bikes and free stands in the bike-share system, and snap-shots from a number of CCTV cameras (see Figure 6). In addition, many travelers can use GPS navigation systems that automatically re-route drivers in response to real-time updates, often taken from other real-time datasets; for example, Google-based GPS (App: ‘Maps – Navigation & Transit’) calculates traffic congestion based on the movement of Android phones.

Sound monitoring and modelling

In 2002 the EU Environmental Noise Directive (2002/49/EC[7]) was issued, designed to measure noise pollution levels in urban areas and on major roads and to trigger necessary noise reduction measures. The directive requires member states to monitor noise levels and share these with the public, and prepare and publish every five years noise maps and noise management action plans. The directive was enshrined in Irish law as the Environmental Noise Regulations (Statutory Instrument No. 140 of 2006). As a consequence, Dublin

Figure 5. Real-time passenger information sign at a bus stop.



Christchurch Car Park currently has 114 spaces (Total Spaces:212)

Figure 6. Travel times for selected road segments, available bikes in bike-share stations, and available car parking spaces as presented in the Dublin Dashboard (http://www.dublindashboard.ie/pages/DublinTravel).

Location
Drumcondra Library

Date range
12/07/2016 to 22/07/2016

Figure 7. Sound levels at Drumcondra Library, Dublin.

City Council (DCC) (as well as the other three Dublin local authorities) is obliged to measure, model and publish noise levels across its jurisdiction. DCC subcontracts this service to a private, Dublin-based start-up company, Sonitus Systems, who deploy an Internet of Things solution using networked sound sensors located in 14 locations (40 across the city as a whole). The sound levels recorded by the monitoring stations are displayed via an interactive map[8] and specific site graphs,[9] enabling the public to read daily and longer-term sound levels for each station, and compare different locations (see Figure 7). As one our interviewees explained:

> '[O]ur system is constantly measuring noise levels, 24/7, it makes an average every five minutes, or every five minutes it logs a reading, and then it uploads that automatically to our server. And we take all that data coming in, a reading every five minutes from 40 sites all over the city, and we turn that into useful information about what is happening in areas around the city by processing it, by averaging it, by comparing it with other sites and by providing a set of tools online to let either our customer or the general public analyze what is happening one day to the next, over time, and look at it in longer-term trends over time. (Start-up entrepreneur #2)

The consequence is that the city now has 'millions and millions of measurements, six metrics taken every five minutes for the last five years at a dozen different points around the city' (company manager), which are made available for scrutiny through a web-based software platform and forms part of the database for noise modelling (see Figure 8). To produce noise maps at a finer resolution than the sound monitors enable, the data are complemented by 'road surface and gradient, number of vehicles and speed of the traffic, positions of buildings and barriers and the topology of the local area' and are modelled using predictive software to produce day-time and night-time maps.[10]

Here, quite literally we have a set of algorhythms at work, algorithmically measuring, processing and analyzing urban sound and its rhythms. As with the traffic management system, the rhythms detected are affected by calibration, initial settings and the equipment used. As one of our interviewees describes with respect to an air quality sensor network:

> Interviewee: It takes time to understand whether sensors work or not. You need to choose the interval in which you retrieve the data. Because if you retrieve them at the second scale, you have plenty of information, but there also can be much noise. If you retrieve them at the hour scale it is more normal but you can

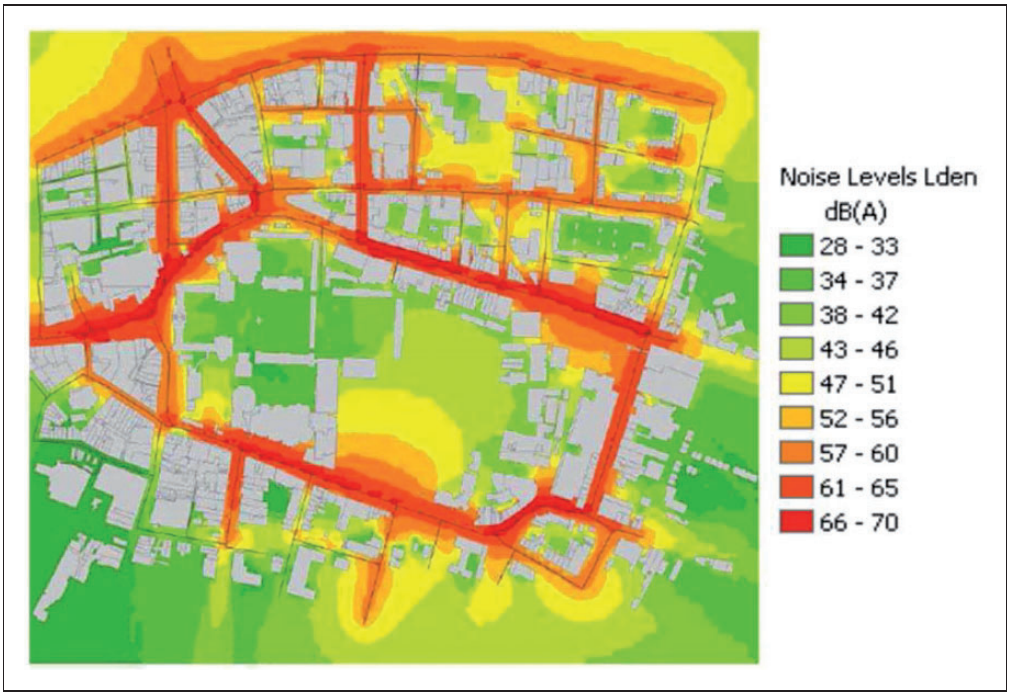


Figure 8. Noise model for part of Dublin (source: http://dublincitynoise.sonitussystems.com/noise-maps.php).

> lose information, so you need to find a compromise, the right balance.
> Interviewer: Also in relation with the times of the city: morning, peak hours, evening...
> Interviewee: Exactly. Then the higher the resolution, the higher the consumption of battery; the more you keep data in the flashcard, the more you have to transmit them. There is a whole series of compromises you need to deal with. (Environmental engineer, University)

The calculation of the measurement interval thus requires a compromise between the resolution of information and noise, and to take into account battery capacity and maintenance. The resolution is also often shaped by the type of communications network deployed to relay data. Sending data via GSM can be expensive over time, encouraging lower resolution transfers. In Dublin, a Low-Power Wide-Area Network (LPWAN) is being tested which allows long range communication at a low bit rate and is specifically designed for battery-powered Internet of Thing devices and to support low cost sensors. In other words, the rhythm and resolution of the data measurement and transfer – every five seconds, every minute, every hour, every day – is technically mediated. Again, calibration is coupled with repetition and produces the refrain that enables the accountability and actionability of data.

Discussion and conclusions: Algorhythmic governance, refrains and rhythm-making

The concept of algorhythmic governance expresses the existence of scalable dynamics generated by the interplay of calibration and repetition that create refrains that make computation, management and policies accountable and actionable. *Rhythm-making* takes place in different organizations and they are ongoing, open, dispersed, loosely connected, performative, prescriptive and manipulable. In rhythmanalytical terms, the SCATS software and the operators in the TMIC, and the Sonitus sound monitoring network and sound modellers, are undertaking rhythmanalysis – that is, they are seeking to measure and reveal the polyrhythms of the city. But they are also rhythm-makers, in that they actively seek to mediate and calibrate repetitions and rhythms in the world – to try and minimize difference and arrhythmia (disruptive, out-of-sync disjunctions) and produce eurhythmia (harmonious, stable, familiar refrain) which in turn produces further difference and possible arrhythmia enacting particular (and unstable) space-times. Similarly, people who access the data produced within both domains through apps, websites and on-street signs seek to undertake their own rhythmanalysis that shapes their space-time decision-making, and whose subsequent actions collectively and cumulatively alter the rhythms of the city.

Our analysis highlights that while both the traffic control room and the sound network enact algorhythmic governance, it is clear that they do so in different ways. Both systems are highly automated with respect to data generation, transmission, processing, analysis and sharing. They differ, however, with respect to their adaptiveness and action.

SCATS is an adaptive system in two respects. First, the regulation of the phases and cycles adapts to the demand at junctions and across the road network and certain priority rules. This process is a form of automated management as defined by Dodge and Kitchin (2007), in which the system makes and enacts automated, automatic and automated decisions. Second, unlike automated management in its pure form, a human controller can intervene, within certain parameters, to over-ride the automated adaptions and re-calibrate the system. In this sense, the system is one of human-on-the-loop (rather than human-off-the-loop), wherein the system works in an automated fashion but under the watch of a human controller who can intervene (Docherty, 2012). Moreover, the system enacts real-time actions and has real-time effects, with the phases and cycles of traffic lights at key junctions being dynamically changed. As a result, every two cycles the length of time vehicles wait at junction updates; the system has immediate material actions designed to produce a desired space-time rhythm. However, due to the polyrhythmic and complex nature of cities, and the mutable cyclicality and linearity of algorhythms, the results are never a perfect flow, but rather a semi-optimal concatenation that seeks to stave off inertia or chaos.

In contrast, the sound network is fixed and non-adaptive beyond periodic system upgrades. The system simply generates sensor measurements, transmits them back to a central database, and updates a set of web-based visualizations. Moreover, it engenders no immediate material action. Instead, the data is used to build up sound profiles of key locations over time and is combined with other data to produce sound models for the city. These data and models are then used as the basis for identifying and implementing noise reduction policies. In other words, algorhythms form the basis of measuring and monitoring noise levels, and for justifying governance interventions, but the system does not directly intervene in action. As such, the noise monitoring networks constitutes a form of algorhythmic governance that is not yet fully automated or self-calibrating.

The two case studies thus reveal two different forms of algorhythmic governance which each enact a different type of rhythmanalysis and perform different kinds of rhythm-making. It is our contention that there are many more forms of algorhythmic governance. The most obvious third form is one where humans are off-the-loop, wherein an algorhythmic system has been delegated the responsibility and authority to process data and make decisions and act upon them without any human input or interaction (Docherty, 2012). Indeed, there is a need to explore further the ways in which algorhythmic governance is co-created by algorithms and actors and the ways in which each shapes the other. Within each form of algorhythmic governance, there will be variability in how the mode of governance of operates and how it is actioned, dependent on a number of factors – data generated, technology (e.g., sensors used, network infrastructure, battery life), epistemic practices, epistemology (mode of analysis, visualization), and forms of regulation and control exercised (in the case of human-off-the-loop varying from automated fines, to altering phases and cycles, to killing people as with military drones).

In each case, a combination of heterogeneous and layered timings and devices, and practices of continuous maintenance and calibration designed to balance and equalize repetitions and minimize difference, is enacted. As our case studies highlight, a number of other issues are also raised. For example, how and where the networks of sensors are set up and calibrated: decisions that establish a traffic cycle of 2 minutes with different phases, or a time frequency of 5 minutes, affects the actionability of data and the capability of actors to monitor, detect and intervene. The sensitivity of sensors, local conditions, scientific norms and handling procedures can add noise to the measurements, which can also be biased and contain error (Kitchin et al., 2015). Indeed, there are always concerns over data fidelity, precision, representativeness, cleanliness, consistency, and reliability of measurements, and the extent to which these affect calculations. Moreover, calibration and filtering the signal from noise is reliant on computational procedures to extract meaningful information, which influence the derived data. And given the polyrhythms and unfolding nature of cities, there is no established or stable norm against which such calibrations are being made; to degree then, adaptive systems such as traffic management are self-organizing, with system rules and human interventions based on a rule of thumb garnered from controller experience.

There are also questions of transparency and accountability with respect to such algorhythmic governance. Within automated systems, the rules for acting on data and making decisions is largely black-boxed, especially for ordinary citizens. Yet it is known that programmers routinely, if unintentionally, change the substance of rules when translating them into computer code, thus altering the regulatory work they do (Citron, 2007–2008). Moreover, weak algorithms and dirty or error-prone data can generate high rates of false positives and baseless decision making. As a result, the result, the 'transparency, accuracy, and political accountability of administrative rulemaking' are potentially lost and are difficult to challenge (Citron, 2007–2008: 1254).

To conclude, there is clearly much more research to be undertaken to more fully chart the nature, workings and forms of algorhythmic governance, the various issues shaping and arising from their use, and how they perform rhythmanalysis and rhythm-work in order to mediate the polymorphic temporal rhythms of urban life. Indeed, the city itself has an institutional and historical 'heartbeat' that interact and is difficult to attune with the real-time one of smart urbanism, as one of our interviewee remarked:

> When you think about the physical city you have to think in terms of the pulse rate being 30 years, a heartbeat in Dublin terms is 30 years because that is how long it takes to conceive of and build a bridge. You are looking at timelines that are not driven by electronic Internet time clocks.... Whereas you talk through problems like homelessness... and that is a very immediate sharp focus problem, depending on government policy it may be more or less of a problem in a particular month, year and so on. So there are many different timelines and tracks within a city. (Manager, large company)

Algorhythmic governance is the (semi)automated endeavour to combine of all these heterogeneous and layered timings and devices, where the effort to calibrate, balance and equalize the heartbeat of the city generates both regulation and interference, entangling 'real-time', past and future, and acting 'at the same time' on different scales.

Acknowledgements

We would like to thank our interviewees and the staff of the traffic control room for their help in conducting the empirical research and answering additional questions. We are also grateful to Charlotte Cabasse Mazel, Marcus Owen, Beth Reddy as well as the editors and the anonymous reviewers for their helpful comments and constructive feedback.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: the Programmable City project, funded by a European Research Council Advanced Investigator award (ERC-2012-AdG-323636-SOFTCITY).

Notes

1. '[T]he space-time for the previous cycle is being compared to the cycle at max-flow to determine if it is under or over-saturated. This is achieved by taking the average space-time at max-flow (t) and multiplying it by the number of vehicles (n), to give a value of T[otal space phase time] for the measured cycle as if it was at max-flow; this is then compared to the actual T recorded for the measured cycle'. (McCann, 2014). For the detailed functions and informatic architecture of SCAT system see McCann (2014).
2. http://www.oed.com/view/Entry/26348#eid10533743
3. http://www.dttas.ie/roads/publications/english/traffic-signs-manual-2010
4. https://www.dublinbus.ie/Your-Journey1/Mobileapps/
5. https://www.dublinbus.ie/RTPI/Sources-of-Real-Time-Information/
6. http://www.dublindashboard.ie
7. http://ec.europa.eu/environment/noise/directive_en.htm
8. http://dublincitynoise.sonitussystems.com/locations.php
9. http://dublincitynoise.sonitussystems.com/charts.php
10. http://dublincitynoise.sonitussystems.com/noise-maps.php

References

Amoore L (2006) Biometric borders: Governing mobilities in the war on terror. *Political Geography* 25: 336–351.

Amoore L (2013) *The Politics of Possibility: Risk and Security Beyond Probability*. Durham, NC: Duke University Press.

Borch C, Hansen KB and Lange A-C (2015) Markets, bodies, and rhythms: A rhythmanalysis of financial markets from open-outcry trading to high-frequency trading. *Environment and Planning D: Society and Space* 33(6): 1080–1097.

Brown S and Capdevila R (1999) Perpetuum mobile: Substance, fame and the sociology of translation. In: Law J and Hassard J (eds) *Actor Network Theory and After*. Oxford: Blackwell, pp. 26–50.

Castells M (1996) *The Network Society*. Oxford: Blackwell.

Citron D (2007–2008) Technological due process. *Washington University Law Review* 85: 1248–1313.

Conlon D (2010) Fascinatin' rhythm(s): Polyrhythmia and the syncopated echoes of the everyday. In: Edensor T (ed.) *Geographies of Rhythm: Nature, Place, Mobilities and Bodies*. Farnham: Ashgate, pp. 71–81.

Crang M (2001) Rhythms of the city: Temporalised space and motion. In: May J and Thrift N (eds) *Timespace: Geographies of Temporality*. London: Routledge, pp. 187–207.

Crang M, Crosbie T and Graham S (2007) Technology, time-space and the remediation of neighbourhood life. *Environment and Planning A* 39: 2405–2422.

Crang M and Graham S (2007) Sentient cities: Ambient intelligence and the politics of urban space. *Information, Communication & Society* 10(6): 789–817.

Deleuze G and Guattari F (1987[1980]) *A Thousand Plateaus*. Translated by B Massumi. Minneapolis: The University of Minnesota Press.

DeNardis L and Musiani F (2016) Governance by infrastructure. In: Musiani F, Cogburn DL, DeNardis L, et al. (eds) *The Turn to Infrastructure in Internet Governance*. New York, NY: Palgrave, pp. 3–21.

Docherty B (2012) *Losing Humanity: The Case Against Killer Robots*. New York, NY: Human Right Watch. Available at: www.hrw.org/sites/default/files/reports/arms1112_ForUpload.pdf (accessed 17 November 2015).

Dodge M and Kitchin R (2007) The automatic management of drivers and driving spaces. *Geoforum* 38(2): 264–275.

Dourish P (2016) Algorithms and their others: Algorithmic culture in context. *Big Data and Society* 3(2): 1–11.

Edensor T (2010a) Introduction: Thinking about rhythm and space. In: Edensor T (ed.) *Geographies of Rhythm: Nature, Place, Mobilities and Bodies*. Farnham: Ashgate, pp. 1–18.

Edensor T (2010b) *Geographies of Rhythm: Nature, Place, Mobilities and Bodies*. Farnham: Ashgate, pp. 1–18.

Edensor T and Holloway J (2008) Rhythmanalysing the coach tour: The ring of Kerry, Ireland. *Transactions of the Institute of British Geographers* 33: 483–501.

Elden S (2004) Rhythmanalysis: An introduction. In: Lefebvre H (ed.) *Rhythmanalysis: Space, Time and Everyday Life*. Translated by S Elden and G Moore. London: Continuum, pp. vii–xv.

Gillespie T (2014) The relevance of algorithms. In: Gillespie T, Boczkowski PJ and Foot KA (eds) *Media Technologies: Essays on Communication, Materiality, and Society*. Cambridge, MA: MIT Press, pp. 167–193.

Gordon E and de Souza e Silva A (2011) *Net Locality: Why Location Matters in a Networked World*. Malden, MA: Wiley-Blackwell.

Graham S (2005) Software-sorted geographies. *Progress in Human Geography* 29(5): 562–580.

Graham S (2011) *Cities Under Siege*. London: Verso.

Hagerstrand T (1970) What about people in regional science? *Regional Science Association Papers* 24(1): 7–21.

Hardie I and MacKenzie D (2007) Assembling an economic actor: The agencement of a Hedge Fund. *The Sociological Review* 55(1): 57–80.

Hassan R and Purser RE (eds) (2007) *24/7: Time and Temporality in the Network Society*. Stanford, CA: Stanford Business Books.

Introna LD (2016) Algorithms, governance, and governmentality: On governing academic writing. *Science, Technology and Human Values* 41(1): 17–49.

Janssen M and Kuk G (2016) The challenges and limits of big data algorithms in technocratic governance. *Government Information Quarterly* 33(3): 371–377.

Jiron P (2010) Repetition and difference: Rhythms and mobile place-making in Santiago de Chile. In: Edensor T (ed.) *Geographies of Rhythm: Nature, Place, Mobilities and Bodies*. Farnham: Ashgate, pp. 129–143.

Kitchin R (2014) The real-time city? Big data and smart urbanism. *GeoJournal* 79(1): 1–14.

Kitchin R (2016) *Getting smarter about smart cities: Improving data privacy and data security*. Data Protection Unit, Department of the Taoiseach, Dublin, Ireland. Available at: http://www.taoiseach.gov.ie/eng/Publications/Publications_2016/Smart_Cities_Report_January_2016.pdf (accessed 3 November 2016).

Kitchin R (2017) Thinking critically about and researching algorithms. *Information, Communication and Society* 20(1): 1–14.

Kitchin R, Coletta C and Gavin MA (2008) Urban informatics, governmentality and the logics of urban control. In: Luque-Ayala A and Marvin S (eds) *Control Room: Nodes in the Networked City*. London: Routledge.

Kitchin R and Dodge M (2011) *Code/Space: Software and Everyday Life*. Cambridge, MA: MIT Press.

Kitchin R, Lauriault TP and McArdle G (2015) Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards. *Regional Studies, Regional Science* 2: 1–28.

Klauser F, Paasche T and Söderström O (2014) Michel Foucault and the smart city: Power dynamics inherent in contemporary governing through code. *Environment and Planning D: Society and Space* 32(5): 869–885.

Kofman E and Lebas E (1996) Lost in transposition. In: Kofman E and Lebas E (eds) *Writings on Cities – Henri Lefebvre*. Oxford: Blackwell, pp. 3–60.

Lefebvre H (1991[1974]) *La production de l'espace*. Paris: Anthropos. Translated by Donald Nicholson-Smith as *The Production of Space*. Oxford: Blackwell.

Lefebvre H (1996) Writings on cities. In: Kofman E and Lebas E (eds) *Writings on Cities – Henri Lefebvre*. Oxford: Blackwell.

Lefebvre H (2004[1992]) *Eléments de rythmanalyse: introduction á la connaissance des rythmes*. Paris: Editions Syllepse. Translated by S Elden and G Moore as *Rhythmanalysis: Space, Time and Everyday Life*. London: Continuum.

Leszczynski A (2015) Spatial big data and anxieties of control. *Environment and Planning D: Society and Space* 33(6): 965–984.

Luque-Ayala A and Marvin S (2016) The maintenance of urban circulation: An operational logic of infrastructural control. *Environment and Planning D: Society and Space* 34(2): 191–208.

McCann B (2014) A review of scats operation and deployment in Dublin. In: *Proceedings of the 19th JCT traffic signal symposium & exhibition*, University of Warwick, Warwick, 18–19 September 2014. JCT Consulting Ltd. Available at: http://www.jctconsultancy.co.uk/Symposium/Symposium2014/PapersForDownload/A%20Review%20of%20SCATS%20Operation%20and%20Deployment%20in%20Dublin.pdf (accessed 7 March 2017).

Mackenzie A (2005) Protocols and the irreducible traces of embodiment. In: Hassan R and Purser RE (eds) *(2007) 24/7: Time and Temporality in the Network Society*. Stanford: Stanford Business Books, pp. 89–105.

Massey D (1992) Politics and space/time. *New Left Review* 196: 65–84.

May J and Thrift N (2001) Introduction. In: May J and Thrift N (eds) *Timespace: Geographies of Temporality*. London: Routledge, pp. 1–46.

Miyazaki S (2012) Algorhythmics: Understanding micro-temporality in computational cultures. *Computational Culture* Issue 2. Available at: http://computationalculture.net/article/algorhythmics-understanding-micro-temporality-in-computational-cultures (accessed 25 June 2014).

Miyazaki S (2013a) AlgoRHYTHMS everywhere: A heuristic approach to everyday technologies. In: Hoogstad JH and Stougaard B (eds) *Of Beat: Pluralizing Rhythm*. Amsterdam: Rodopi, pp. 135–148.

Miyazaki S (2013b) Urban sounds unheard-of: A media archaeology of ubiquitous infospheres. *Continuum: Journal of Media & Cultural Studies* 27(4): 514–522.

Palmer M and Jones O (2014) On breathing and geography: Explorations of data sonifications of timespace processes with illustrating examples from a tidally dynamic landscape (Severn Estuary, UK). *Environment and Planning A* 46: 222–240.

Pasquale F (2015) *The Black Box Society: The Secret Algorithms That Control Money and Information*. Cambridge, MA: Harvard University Press.

Schwanen T (2007) Matter(s) of interest: Artefacts, spacing and timing. *Geografiska. Annaler* 89B(1): 9–22.

Spinney J (2010) Improvising rhythms: Re-reading urban time and space through everyday practices of cycling. In: Edensor T (ed.) *Geographies of Rhythm: Nature, Place, Mobilities and Bodies*. Farnham: Ashgate, pp. 113–127.

Thrift N and French S (2002) The automatic production of space. *Transactions of the Institute of British Geographers* 27(3): 309–335.

Townsend AM (2000) Life in the real-time city: Mobile telephones and urban metabolism. *Journal of Urban Technology* 7(2): 85–104.

Townsend A (2013) *Smart Cities: Big data, Civic Hackers, and the Quest for a New Utopia*. New York, NY: W.W. Norton & Co.

Walker G (2014) The dynamics of energy demand: Change, rhythm and synchronicity. *Energy Research & Social Science* 1: 49–55.

Willis KS (2016) *Netspaces: Space and Place in a Networked World*. Farnham: Ashgate.