Out of Order

Understanding Repair and Maintenance

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> What would our lives be like if we took earthworms seriously, took the ground under our feet rather than the skies above our heads, as the place to look as well as, eventually, as the place to be? It is as though we have been pointed in the wrong direction.

SO WRITES Adam Phillips (1999: 60–1), as he tries to paint a world in which the maintenance of the earth provided by the humble earthworm is given the space it deserves, that constant process of mass movement through ingestion which in turn helps to produce the fertile soil on which we all directly or indirectly depend for sustenance. Fittingly, this process of bioturbation was first described by Charles Darwin in a paper in 1838 and then expanded upon in his last book (1881/1985).[1] As Phillips argues, in describing the constant and unremitting gustatory work of a supposedly 'lower' form of life, Darwin was trying to assert how important humble biological processes could be – and, equally, how easily they could be neglected by those who were sure that they knew what the 'higher' forms of life were.[2]

In this article, we want to make a rather similar move by considering all the processes of maintenance and repair that keep modern societies going. These processes can be likened to the social equivalent of the humble earthworm in their remorseless and necessary character[3] – and in the way in which they have been neglected by nearly all commentators as somehow beneath their notice. Our intention is to bring these processes out into the light and to make them into the object of the systematic and sustained attention that they surely deserve to be, since they are the main means by which the constant decay of the world is held off. Our laboratory will be the contemporary city, which hosts and is to a large extent defined by the myriad functions of maintenance and repair which themselves produce much of

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what might be regarded as the stuff of urban phenomenology. Think only of some of the familiar sounds of the city as an instance: from the sirens denoting accidents, to the noises of pneumatic drills denoting the constant upkeep of the roads, through the echoing clanks and hisses of the tyre and clutch replacement workshop, denoting the constant work needed just to keep cars going.

To begin the resurrection of the activities of repair and maintenance in the social sciences, we have written an article that is in five sections which themselves plot out an argument. In the first section, we will make the theoretical case for the humble but vital processes of repair and maintenance as the 'ready' of 'ready-to-hand'. In the subsequent sections, we will turn towards the key manifestation of social systems of maintenance and repair, namely modern cities. Thus the second section inquires into why the business of maintenance and repair in cities has so often been neglected. The third and fourth sections provide examples of particular sub-systems of maintenance and repair, namely electricity supply, and particularly its intersection with information and communications technology (ICT), and automobility. Then, in the concluding part of the article, we will argue that repair and maintenance activities have not just more grip but more emancipatory potential than may be thought by those who want to write them off as simply mundane or slavishly repetitive.

Ready-to-hand/Facilitating the World

We want to start our account of the importance of repair and maintenance by calling on the work of Heidegger. This may seem an odd move to some but hopefully its logic will become clear. Influentially, Heidegger set out a notion of the world as ready-to-hand, as involved in practices – concernful dealings with the world – that always involve things used in particular 'handy' ways: generally speaking, human beings do not focus on a tool or a piece of equipment but on the work in which they have become engaged. But, it might be argued, Heidegger placed much more emphasis on 'to hand' than 'ready'. In most of his work, and that of the subsequent phenomenological tradition, it tends to be assumed that the world is ready. But that is not always the case, as Heidegger himself acknowledged. Things only come into visible focus as things when they become inoperable – they break or stutter and they then become the object of attention. The background is thereby foregrounded.

> Things, in short, disclose a world. When somebody uses a tool or piece of equipment, a referential structure comes about in which the object produced, the material out of which it is made, the future user, and the environment in which it has a place are related to each other. But that this is so, according to Heidegger, generally appears only when a handy or ready to hand tool or piece of equipment breaks down. When this happens, the tool suddenly demands attention for itself. The reliable dealings we are used to having with the tool are ruptured, and instead of withdrawing from our attention the tool suddenly forces itself upon us. Someone sits at a word processor focused on

> the text at hand and all of a sudden the computer freezes. The trustworthy world that developed around the computer – the open book, the keyboard, the screen, the cup of coffee; in short, the entire mutually referring network that Heidegger calls a world – is abruptly destroyed. The computer changes from being one of the handy or ready-to-hand that shape this world to what Heidegger calls something *vorhanden*: 'objectively present' in the newer translation, or 'present-at-hand' in the older. Its transparency is transformed into opacity. The computer can no longer be utilized in the practice of writing, but abruptly demands interaction with itself. The relation with the world around the computer that took place 'through' it is disturbed. Only when it starts up again and everything works without a hitch is the world that was destroyed again restored. (Verbeek, 2004: 79–80)

But it is in this space between breakdown and restoration of the practical equilibrium – between the visible (that is, 'broken') tool and the concealed tool – that repair and maintenance, makes its bid for significance. For without that capacity, the world cannot go on, cannot become ready-to-hand again.[4] In other words, repair and maintenance is rather more significant than the practical models of the onflow of everyday life that have now become so significant in the social sciences and humanities are willing to own to. Repair and maintenance is reality's bridge from withdrawn execution to the brokenness bound up in purposes that it once served, a 'visible termination of its underground action' (Harman, 2002: 26). So what are the main components of repair and maintenance?

To begin with, we want to understand the many processes of maintenance and repair as an illustration of the power of things to form a common material substrate, which is always on and which forms the equivalent of a Heideggerian background (Thrift, 2004a, 2004b, 2005a, 2005b). This carpet of ongoing maintenance and repair is characterized by a set of qualities. First, it relies on the power of things and these things cannot be reduced to the sum of a set of social forces: 'what a thing does, the way in which a thing is present as a thing, cannot be reduced to something non-thingly and must be conceived from the thing itself' (Verbeek, 2004: 89). Things are not just formed matter, they are transductions with many conditions of possibility and their own forms of intentionality. Second, these things are often pluricultural, that is, they have become so common that they have come to play a role in the everyday life of almost everyone, weaving various different cultures together through their mere existence (Ihde, 1993). Third, in all likelihood, the number of things has been proliferating, becoming more complex and becoming composed from an ever greater range of materials, thus requiring ever more maintenance and repair (including low-level maintenance like cleaning) (Dant, 2004). Fourth, because this progressively more populated background is always on, the importance of repair and maintenance becomes even more crucial. Breakdowns come to have an existential quality to them, since they may well affect large numbers of people simultaneously. They produce a decisional burden which itself requires a comprehensive structure of repair and maintenance, which must be able to become available all but instantaneously. Fifth, and relatedly, it becomes increasingly difficult to define what the 'thing' is that is being maintained and repaired. Is it the thing itself, or the negotiated order that surrounds it, or some 'larger' entity? Similarly, it can be argued that the accidents that stem from so many breakdowns are not aberrant but are a part of the thing itself. To invent the train is to invent the train crash, to invent the plane is to invent the plane crash, and so on (Lotringer and Virilio, 2003).

But, equally importantly, maintenance and repair also illustrate the importance of human labour and ingenuity. When breakdowns and malfunctions occur, it is not necessarily the case that they can be easily fixed. The reason for the breakdown may be opaque (especially as technological systems become more complex), the restoration may be too urgent for usual channels and procedures to be followed, the replacement parts may not be quite right but need to be made to fit. Orr's (1996), Downey's (1998) and Henke's (2000) ethnographies of technical workers, which draw on Garfinkel's (1967) ethnomethodological work on the repair of language through conversation, show the importance of maintenance and repair born out of the ever-present presence of failure and malfunction and error – and the consequent opportunity to learn from them. Thus Orr's technical representatives have built up a vast practical archive of fudges and shortcuts, while Downey's student computer engineers actually knew that they had produced living design programs only when these programs produced bugs. In Downey's (1998: 239) words: 'I would wager that [actions that try to filter out human ingenuity] always hide important ways in which humans contributed more than labor and ways in which technologies introduced more than simple automation of human activities.' Most particularly, as Henke (2000) shows, the quality of improvisation is key since fault-finding and repair is a process of ongoing, situated inquiry. Improvisation allows the work of maintenance and repair to go on when things may seem bleak and it takes in a whole series of responses, from simple repetition (such as trying it again) through to attempts to improve communication so as to be clear exactly what the problem is, through disagreement over causes, through to complex theorizing, responses which are often the result of long and complex apprenticeships and other means of teaching (Henke, 2000; Suchman, 1987). Yet, at the same time, these ethnographies also show that the way in which maintenance and repair is officially represented in most bureaucracies as subordinate hides this work from view, for example in worksheets that cannot acknowledge this knowledge.

It is important to understand, however, that the tightly drawn infrastructural networks that characterize many contemporary societies routinely blur the distinction between things and human actors, producing hybrid networks that can be thought of as illustrations of 'inhuman' approaches like actor-network theory. Indeed, it might be thought that such approaches are but the natural cognitive sediment from the kinds of comfortable existences that large infrastructural networks now make possible, characterized by knowledges and procedures that are able to take on a life of their own through fortuitous mixes of bodies and machines in new kinds of actant which are often themselves highly heterogeneous.[5] Such thoughts on new forms of ecology-in-action are only underlined by the way in which new materials are constantly incorporated into these networks and by how many infrastructural networks now have limited elements of automatic self-repair built into them. For example, many machine systems are able to send messages that one or more of their components has broken down and needs repairing. The ambition is clearly to go farther: for example, one of the goals of modern computer science has become the creation of so-called self-healing systems. Such developments are aided as well by the way in which many modern corporate organizations are consciously turning themselves into 'consolidators' or 'integrators' of multiple flows of goods, information and money. Through the intervention of enterprise resource management software (Head, 2003), they have become proficient in linking and standardizing a whole range of activities; 'supply chain management, brokerage services, trade financing, reverse logistics, critical-parts distribution, global freight, e-commerce tools, online tracking, and package delivery' (Thackara, 2005: 57).

To summarize the argument so far, perhaps we have been looking in the wrong place. Perhaps we should have been looking at breakdown and failure as no longer atypical and therefore only worth addressing if they result in catastrophe and, instead, at breakdown and failure as the means by which societies learn and learn to re-produce (Petroski, 2006). Disconnection produces learning, adaptation and improvisation. All infrastructural systems are prone to error and neglect and breakage and failure, whether as a result of erosion or decay or vandalism or even sabotage. Indeed, many such systems are premised on a certain degree of error or neglect or breakage or failure as a normal condition of their existence (Petroski, 1985). But when things break down, new solutions may be invented. Indeed, there is some evidence to suggest that this kind of piece-by-piece adaptation is a leading cause of innovation, acting as a continuous feedback loop of experimentation which, through many small increments in practical knowledge, can produce large changes. Seen in this light, 'maintenance is learning' (Brand, 1994: 127). And, if this is the case, then the multifarious activities of repair and maintenance become not just secondary and derivative but pivotal. They become one of our chief means of seeing and understanding the world.

This argument, in turn, allows us to foreground three vital elements of the world that it would be much easier to see if maintenance and repair was taken into our accounts. The first is decay. The world constantly decays. Moisture gets in. Damp hangs around. Ice expands joints. Surfaces wear thin. Particles fall out of suspension. Materials rot.[6] Insects breed.[7] Animals chew.[8] All kinds of wildlife war with all kinds of fabric.[9] Humans make errors.[10] Each process of dilapidation does its special harm and releases new 'wastes' (Hetherington, 2004; Thompson, 1979). This entropic tendency can be likened to Freud's notion of a death instinct, a force that undoes connections and destroys life: the world is involved in a continuous dying that can only be fended off by constant repair and maintenance. A similar insight can be found in the architectural literature in the argument that buildings are flows that are always in a state of flux as they strive constantly to fend off decay, diverse means of, in effect, choosing particular means of dying. Architectures are morphogenetic figures forged in time, tacking against a general entropic tendency, an insight which is mutating into a new generation of flow architecture.

The second element is the way in which maintenance and repair can itself be a vital source of variation, improvisation and innovation. Repair and maintenance does not have to mean exact restoration. Think only of the bodged job, which still allows something to continue functioning but probably at a lower level; the upgrade, which allows something to take on new features which keep it contemporary; the cannibalization and recycling of materials, which allows at least one recombined object to carry on, formed from the bones of its fellows; or the complete rebuild, which allows something to continue in near pristine condition. And what starts out as repair may soon become improvement, innovation, even growth. The examples are legion: the constant tinkering of consumers with consumer goods, which can certainly lead to customization and may even lead to redefinition, as in the case of the early automobile (Franz, 2005). In turn, such constant tinkering means that any repair and maintenance is likely to be idiosyncratic too.[11]

Returning to the issue of architecture exemplifies this point (Brand, 1994). While many urban buildings, especially in the global South, are auto-constructed and continually adapted – even architecturally designed buildings are constantly being tinkered with. This produces gradual but distinctive changes in their layout, skin and appearance. Very often, the issues raised by this continual repair and adaptation of buildings are actually completely ignored in the original design process.

Yet Brand, in his book *How Buildings Learn* (1994), documents how only about a third of the US housing stock is well-maintained. The rest of it is in a state of slower or faster decay. Estimates from the most recent English House Condition Survey (ODPM, 2005) conclude that in 2003 31 percent (5.3 million) of the whole English housing stock consisted of 'non-decent' homes while 5 percent of homes (1 million) were 'unfit'. These figures cannot be exactly mapped on to state of repair but they are at least indicative. Commercial buildings are often, in certain senses, in even worse condition, in part because architects themselves rarely consider or take into their designs the business of maintenance and repair: 'they see the people who do the maintaining as blue collar illiterates and the process of upkeep as trivial, not a part of design concerns' (Brand, 1994: 112). Thus, one:

> . . . survey of fifty-eight new business buildings near London [found that] 'a staggering one-fifth of the sample said that the need to clean their windows had not even been considered during the design and construction of the

> building'. Also light fixtures in the grand lobbies were unreachable for lamp replacement, and internal drains from the flat roofs had no access hatches for inspection and cleaning. (1994: 112)

The final element is the sheer amount of economic activity – usually ignored in accounts of 'global'[12] cities – generated by repair and maintenance. In the United States, for example, there were fully 5.82 million people engaged in 'Installation, Maintenance and Repair' (IMR) occupations in 2000. This figure was expected to rise to 6.48 million by 2010, a growth rate of 11.4 percent. These jobs constituted 4 percent of all jobs in the USA, making the sector one of the six most important service industry occupational groups (DPE, 2003). While these jobs are decentralizing, following wider exurbanization trends, as Table 1 shows, IMR jobs still retain strong metropolitan concentrations.

To summarize once more, the problem with contemporary social theory is that it has predominantly theorized connection and assembly. But there are good reasons to think that, in the overall scheme of things, disconnection and disassembly are just as important in that they resist entities' means of enacting themselves: failure is key. That said, disconnection is only possible if connection, or the possibility of connection, is present, if a system of forces can be formed (Harman, 2002). But a knowledge of systems of partial connection is only just being formed (Strathern, 2004) and therefore, like architecture, social theory still struggles to take maintenance and repair into account.

What seems certain is that the main instance of a knot of ongoing work of maintenance and repair to be found in the world currently is the contemporary city. The city is able to reproduce itself because of never-ending

Table 1 Employment change in 'Installation, Maintenance and Repair' jobs for selected US metropolitan economies and nationally, 1999–2003

Metropolitan Area/Date	*1999*	*2002*	*2003*
Atlanta MSA	80,300	94,220	97,280
Boston	67,460	62,530	61,090
Chicago MSA	125,590	132,850	135,960
Los Angeles Long Beach MSA	120,250	132,290	132,440
Miami MSA	44,380	38,680	38,830
New York MSA	105,690	137,400	134,990
San Diego MSA	42,460	44,600	45,540
San Francisco MSA	33,770	33,580	30,270
US National Economy	5,140,210	5,215,970	5,226,080

MSA = Metropolitan Statistical Area
Source: US Department of Labor, Bureau of Statistics, Occupational Employment Statistics, (http://www.bls.gov/oes/oes_dl.htm)

activities of repair and maintenance, which are not just incidental but provide a good part of its dynamic, as they continually rinse away breakdowns. In what follows, we will investigate these activities in some detail by reference to a series of infrastructural systems, starting with the most general case and working through to two more specific examples.

The Myth of Order: Imagining Cities of Maintenance and Repair

The preceding discussion raises a key question: how can we understand the remarkable neglect of the massive and continuous work that is necessary to sustain the complex infrastructural systems that, paradoxically, are so widely emphasized in writings on the nature of contemporary 'globalized' cities? In what follows, we want to argue that four points help explain this apparent paradox.

The Construction of 'Infrastructure'

First, the very fact that certain technosocial complexes emerge that are deemed to be 'infrastructure' often works to undermine their cultural visibility. This veiling of the multitudinous technological circuits of the city as standardized, normalized and immanent 'infrastructure' thus tends to work to deflect attention from cities of repair. For Susan Leigh-Star (1999: 381–2) such 'infrastructure' has nine key characteristics. It is embedded (i.e. 'sunk into other structures', 1999: 381); transparent ('it does not need to be re-invented each time or assembled for each task'); offers temporal or spatial reach or scope; is learned by its users; is linked to conventions of practice (e.g. routines of electricity use); embodies standards; is built on an installed base of sunk capital; is fixed in modular increments, not built all at once or globally; and, as we have already suggested, tends to become visible upon breakdown.

The last point is crucial for our discussion. For, as Leigh-Star argues, making the Heideggerian point once again, infrastructure systems are often physically and metaphorically veiled beneath the surface of urban life (Kaika and Swyngedouw, 2000). They only tend to become manifest when they cease to function or when the flows sustained by them are interrupted. At such moments, in Erving Goffman's (1959) terms, the built environment's 'backstage' becomes momentarily 'frontstaged' (Henke, 2000). The sudden absence of infrastructural flow creates visibility, just as the continued, normalized use of infrastructures creates a deep taken-for-grantedness and invisibility. Sociologists of science and technology call this latter process 'black boxing'. Here 'black boxes' 'are . . . settled items whose users and colleagues (human and non-human) act in ways which are unchallenging to the technology' (Hinchcliffe, 1996: 665). Thus, interruptions in infrastructural connection can be seen as form of 'unblackboxing'.

> The normally invisible quality of working infrastructure becomes visible when it breaks: the server is down, the bridge washes out, there is a power

> blackout. Even when there are back up mechanisms or procedures, their existence further highlights the invisible infrastructure. (Leigh-Star, 1999: 382)

As David Perry suggests, therefore, it follows that, when infrastructure networks 'work best, they are noticed least of all' (1995: 2).

Catastrophic Preoccupations and Cascading Effects

Second, attention to the need for repair and maintenance of infrastructures tends only to occur after catastrophic, rather than prosaic failures. Large-scale, cascading failures, particularly between electricity and transport outages and other systems, demonstrate, following the influential work of Charles Perrow (1999) on Normal Accidents, that tightly coupled infrastructures 'predictably fail but in unpredictable ways' (Little, 2002: 113). Such failures can have many orders of cascading effects. For example, Little (2002: 111) recounts how, in May 1998, the failure of just one satellite terminated the operation of 80 percent of all US pagers, disrupted ATM and credit card transactions systems, interrupted emergency health-care communications systems and brought chaos to the complex, Just-in-Time systems in place in health-care systems.

Thus, dominant concerns tend to be with the spectacular collapse of whole cities, societies or civilizations, rather then the mundane interruptions and repairs that constitute the quotidian existence of urban dwellers (see, for example, Schneider and Susser, 2003; Vale and Campanella, 2005). We encounter endless fantasies of cyberpunk decay (Sponster, 1992), annihilated cities and complete societal breakdowns rather than swarming masses of repair workers tinkering with the prosaic technicalities of urban life. We have mass disasters and loss of life rather than the improvised coping strategies of users and providers. And we rehearse the millennial speculations of endless predictions of apocalypse by 'cyberterror' (Mitchell and Townsend, 2005) rather than the endless and deeply prosaic software glitches, crashes and the continuous repair necessary to run a simple Windows PC, a city electrical system or an organizational computer network.

In other words, we confront what Josef Konvitz (1990: 62) – writing about the impacts of Allied bombing on the infrastructures of German cities in the Second World War – has called 'the myth of terrible vulnerability' (see Vale and Campanella, 2005). Konvitz argues that, by emphasizing the catastrophic urban impacts of disaster, collapse or warfare, and simultaneously neglecting the way in which the often remarkable resilience of urban infrastructure combines with continuous and prosaic efforts at repair, urban literatures tend to radically overemphasize the vulnerabilities of cities to complete, sustained and irrevocable collapse.

In the process, the continuities between the hidden and ongoing cultures of repair that characterize urban life outside of catastrophic states, and the efforts to overcome natural or human-crafted catastrophe, tend to be dramatically underplayed. We would argue, for example, that the celebrated efforts of systems engineers to bring back web, mobile, data, financial and TV services to the world's most connected urban place – Manhattan – after the 11 September 2001 attacks, merely constituted concerted strategies that built on the continuous processes of management and repair that allow such usually invisible systems to exist in the first place (Mitchell and Townsend, 2005). The remarkable ways in which cities 'rise again' after catastrophe thus have a great deal to do with the ways in which cities are being continually repaired outside more cataclysmic periods (Graham, 2004).

The Myth of 'Infrastructure' as Fixed and Stable Emplacement

Third, the 'black boxing' of infrastructural systems, and the failure of their users to see beyond the flowing tap, the car ignition, the computer screen, the telephone handset or the burning stove, to the empire of functions 'behind' the working service, has further important implications for the imaginations of urban infrastructure. Cultures of normalized and taken-for-granted infrastructure use sustain widespread assumptions that urban 'infrastructure' is somehow a material and utterly fixed assemblage of hard technologies embedded stably in place, which is characterized by perfect order, completeness, immanence and internal homogeneity rather than leaky, partial and heterogeneous entities.

Thus, the inherent and continuous unreliabilities within all infrastructure systems, which necessitate continuous efforts of repair and maintenance to actually allow them to sustain the distantiated connections and flows that they are designed to deliver, still tend to be rendered invisible both culturally and analytically. Indeed, it often seems that the more unreliable the technology, the less it is commented on. Yet it might be argued that most technologies go through a period – which may be an extended one – when they do not 'mesh' and their components are unreliable. Thus, for at least 80 years, automobiles were susceptible to breakdown on a regular cycle, even with all the labour of servicing that might be put in to maintaining them. Whole generations had to become expert at changing oil, mending broken fan belts and replacing spark plugs, as well as makeshift roadside repairs (such as giving the starter motor a good thump). It was only with the advent of a new generation of automobiles, heavily reliant on electronic monitoring, that reliability improved. Nowadays, information and communications technologies have largely replaced the system of automobility as both the most central and yet the most likely to break down, not least because of design flaws that are widely acknowledged but seem to be subject to a law of inertia (Norman, 1998). Whole generations are becoming expert at rebooting, defragging and downloading new security patches. But the common reliance on teleological and deterministic notions, and master narratives, depicting gigantic step-like processes of societal evolution, where 'steam-age' infrastructures give way completely and quickly to 'motor age', 'nuclear age' or 'digital age' ones, add to a sense of the infrastructural palimpsests sustaining cities as being homogeneous, utterly internally coherent and singular machinic systems that are somehow installed *en masse* as if by magic (Stivers, 1999) – to function automatically, and purely, until they are replaced as a whole by some new technoscientific order.

(Re)Normalizing Interruption? The Neglect of Global South Cities

The final reason for the neglect of cities of repair is the continuing failure to satisfactorily incorporate global South urbanism within the dominant discourse of 'urban studies' (Robinson, 2005). For, in global South cities, the deep infrastructural ideologies of the West – which tend to normalize a ubiquitously networked urbanism and work to deny the very possibility of spaces and times when networks are not available, or do not function – have long been utterly untenable. In most of the mega-cities of the global South, for example, the fact that urban life is the result of continuous efforts of infrastructural improvisation and repair is too overwhelming and visible to be ignored. Large swathes of urban economies, both formal and informal, are constituted through efforts to deal with continual interruptions of flow via the provision of back-up services that are able to deal with the continuous collapses of mainstream systems that sustain major economic sectors: personalized boreholes, generators, 'illegal' taps of power and water flow, satellite access points and so on. Endless improvisation surrounds the distribution of scarce water, sanitation, communications, Internet, energy and transport services existing beyond the limited confines of officially sanctioned or contracted users. Many economic sectors are dominated by the question of how the modern and 'competitive' business and logistics modes demanded by transnational economic integration and logistics chains can be sustained against a background of unreliable, patchy and continuously interrupted infrastructure supply (see, for example, Gulyani, 2001). In global South cities, in short, it is often impossible to ignore that the very technosocial architectures of urban life are heavily dominated by, and constituted through, a giant system of repair and improvisation.

With the liberalization, privatization and ageing of infrastructure in the global North sometimes leading to substantial interruptions of service, coupled with a widespread withdrawal of profit-draining back-up systems, the always oversimplified distinctions between the cities of the global North and South are beginning to lessen. As regulated and universal service monopolies are replaced or complemented by liberalized infrastructure patchworks in many global North cities, so universal social, spatial or temporal access to reliable infrastructure services is being undermined, along with wider social contracts or Keynesian imaginations of networked space-economies (Rochlin, 2001).

'We Are All Hostages to Electricity'

In many ways, the inseparable nexus between electricity systems and computer systems presents a particularly useful first example of the massive and largely ignored efforts at continuous repair intrinsic to modern urban life. As suggested earlier, beneath the techo-boosterism of the 'new economy', the realities of using contemporary computer systems is, in many ways, constituted through continuous repair and maintenance. The Y2K 'crisis', in particular, hammered home the fact that contemporary ICT systems are not 'shining cities on a hill – perfect and ever new – but something more akin to an old farmhouse built bit by bit by non-union carpenters' (Ullman, 1999: 126). 'Glitches, patches, crashes', the crisis revealed, were 'as inherent to the process of creating an intelligent electronic system as is the finely tuned program, the gee-whizz pleasure of messages sent around the world at light speed' (1999: 126). The fact that, during the Y2K crisis, even computer and software engineers often had little idea of the full archaeological sedimentation of decades worth of software within their computer networks underlined the 'near immortality of computer software' (1999: 126) and the fact that the resulting systems were inevitably going to be unreliable to an often unknown extent (Thrift and French, 2002). In the event, only the largest concerted repair operation in human history, in the years leading up the turn of the millennium, was able to avert the mass failure of a whole host of transnational ICT systems and the interdependent infrastructures that they sustain.

Clearly, then, a large amount of any investment of time and money in keeping an IT system running is inevitably spent confronting the need for continuous software and hardware upgrades and maintenance: installing software patches to iron out a continuous stream of identified flaws; addressing the malignant code that is continually unleashed into the world; organizing secure back-up systems to maintain data in the event of a major crash; and training and equipping the staff, facilities and services to offer such continuous repair services.[13] To take just one example, within Metropolitan Chicago in 2003, 'computer maintenance and repair' constituted 4 percent of all jobs in the city (5679 jobs in all) (WBMC, 2003).

Moreover, a burgeoning universe of software support and call centre help-lines, spread right across the world to service the major markets of Northern metropolitan areas, constitutes one of the world's fastest-growing industries. Here we confront transnationally configured networks, organized through computer systems, which link consumers in the global North to advisers in the global South, and whose very raison d'être is the continual requirement of users to deal with the mass, routine, failure in computer systems. Spurred on by 9/11, new urban landscapes of repair and maintenance have even started emerging around the cores of the world's great cities, as emergency computer centres, hardened and windowless like Cold War bunkers, are built to be occupied within minutes in the event of a major disruption or crisis.

The mutual constitution of electronic and electrical systems brings a further crucial twist to the continuous repair that brings computerization into being. Every microprocessor and electronic conduit is electrically powered, and, these days, electricity generating systems are themselves operated through complex computer networks. Electricity, moreover, can neither be stored in significant quantities nor switched down particular paths. Instead, it must be generated continuously so that it flows freely, spreading out along all available avenues of supply. The upshot is that computer systems generate enormous demands for electrical power that must be continuously generated and supplied. Some of these demands arise in aggregate, as in the case of the millions of desktop PCs whirring away in standby mode. Other demands are much more concentrated. For example, by one estimate (Thackara, 2005), a single server farm consumes as much electrical power as a city the size of Honolulu. Indeed, the concentration of new server farms in and around the most important high-tech cities has often created major load problems on ancient and often decaying electricity grids and generating systems not designed for such requirements.

The result of this deepening electric-electronic nexus is that we are 'all hostages to electricity', as Leslie (1999: 119–23) puts it. Indeed, it is by concentrating on the material architectures of electricity generation and supply that, in many ways, we can begin to 'see' 'cyberspace' for what it is – not an ethereal domain of 'virtual' bits and bytes, but a gigantic, materialized and electrically powered system requiring massive amounts of continuous and concerted maintenance and repair (Carroll, 2001):

> . . . the computer tool is housed in an electrical building connected to the electrical power system. Together this infrastructure materially represents and sustains the *trompe l'oeil* of otherworldly immateriality whilst simultaneously depending upon a physical assemblage of wires, plugs, and sockets to distribution lines and poles, transformers, transmission towers, and electrical power plants. Without these extensions, Cyberspace would not exist. . . . Cyberspace ceases to exist without electricity. (2001: 3–7)

With continuous, '24/7', computerized interactions and transactions in all economic sectors a prime feature of the techno-economic changes which surround globalization, disruptions to electrical supply thus become all the more debilitating. Studying moments of power loss, moreover, helps to reveal the tensions between usually hidden infrastructures of supply, the cultures of consumption and coping amongst users of power, and the complex politics surrounding interruption, regulation, repair and maintenance (Luke, 2003). In cities of the global South, as we suggested earlier, regular electricity interruption is a fact of life and all users work overtime to develop ways of coping with the predictable or unpredictable losses of power. In addition, the poor reliability of electricity supply requires major firms in such cities to adopt elaborate strategies which guarantee that the electricity necessary to sustain their participation in transnationally organized, just-in-time supply and production chains, through a proliferation of small, corporately owned generating stations and major back-up generators (Gulyani, 2001). Continuous brown-outs, as crumbling infrastructure confronts burgeoning demand and often predatory privatization, serve to puncture the hype that particular cities are necessarily becoming the new iconic 'global' cities.

In cities of the global North, meanwhile, assumptions of reliable and continuous electricity supply have recently been severely eroded by the growing frequency of major power cuts. These have occurred as the increase in electricity demands caused primarily by the growth of ICT and air-conditioning use (see Shove, 2003) have combined with the emergence of liberalized and increasingly interdependent and transnational supply regimes. The result has often been significant reductions in the reliability of electricity supply. Each interruption – including the 'rolling blackouts' in California in January 2001 and the catastrophic failures in the north-eastern USA and Canada on 14 August 2003, and in Italy in September of that year – quickly became formal states of emergency. They caused major economic disruption as the tightly coupled production, distribution, communication and consumption systems that characterize contemporary capitalist divisions of labour ground to a halt. This, in turn, led to a rapid growth in efforts by citizens, firms, and city and state authorities to put in place the sorts of coping strategies, contingency and 'critical infrastructure protection' plans, back-up generator systems and new insurance policies that have long been common in the global South. Finally, these events ensured that the extremely low levels of research and development, maintenance and investment put in to repairing and sustaining energy infrastructures has risen significantly across Western nations. Here, new notions of repair and maintenance are quickly emerging, based on building 'intelligent' electric supply systems which have computerized sensors and automated diagnostic systems that will allow 'self-healing' so that any disruptions are quickly localized, rather than cascading through multiple supply networks, as occurred in August 2003.

What these events reveal most powerfully, however, are the political economies surrounding the application of neoliberal economic ideologies to networked infrastructures, and a complete rebuttal of the subtle cultures of repair which actually allow complex technosocial systems like electricity to work. While debates surrounding energy liberalization have been dominated by abstract neoclassical economic theorizing and discussions of new energy sources, the repair and maintenance of the ageing physical infrastructure grids necessary to continually and reliably distribute the power sources to the plugs and sockets of users has been all but ignored (Van Vliet et al., 2005). 'The rationale behind electricity deregulation', writes Steve Nadis (2004: n.p.), 'is to encourage greater competition among generators, whilst offering users extra choice. But there has been a problem in the middle: the grid and how to use it.'

The day after the 14 August blackout, the *New York Times* front page declared starkly that the United States was 'a major superpower with a Third-World electric grid'. 'Our grid', it continued, 'is antiquated. It needs serious modernisation' (cited in Luke, 2003, 2). In a post mortem of this crisis, a workshop on electricity reliability found that, remarkably, total research and development (R&D) across the electric supply system in the whole of the US amounted to less than $20 million a year. This constituted less than 0.0025 percent of total US R&D, a level that amounted to an investment of less than 0.01 percent of the total sales in the electricity industry (compared to nearly 13 percent in the computer industry, for example) (Mittelstadt et al., 2003).

Electricity deregulation in the USA had actually ignored the economic and geographical fundamentals of an industry that necessitates reliable, material connectivities between generation and use; that is prone to cascading and spiralling failure as transcontinental and transnational markets in supply are established within 'complex interactive networks', with dramatic, unintended consequences, and where the hard infrastructures are ageing and organized with a baroque level of complexity and local fragmentation. 'As the power network becomes heavily loaded with [the] long distance transfers' created by the construction of electricity markets, one analysis of the August blackouts concluded, 'the already complex system dynamics become ever more vulnerable. In a vulnerable system, a simple incident such as an equipment failure can lead to a cascading sequence of events, leading to widespread blackouts' (Mittelstadt et al., 2003: 17).

Why Automobility Keeps Going

Let us move to one other urban icon for our second example. As Urry has pointed out, one of the key systems of modern life is automobility (Featherstone et al., 2005). Yet, to match the wider lacuna in the social sciences, one of its key aspects – maintenance and repair – is constantly overlooked. But it is possible to argue that this system is what keeps automobility going. Three examples of the various sub-systems of automobile maintenance and repair out of the many that are available will serve to make the point.

The first is roadside repair. Until recently, when automobiles started to become more reliable, automobiles had to be surrounded by large numbers of organizations that could engage in repair. A large penumbra of garages and other repair institutions was necessary to keep cars on the road. In the UK, as elsewhere, the economic significance of automobile repair is still growing rapidly, despite the increasing reliability of cars. Indeed, the number of enterprises almost doubled between 1995 and 2003 and turnover grew by a third, presumably because of the growing number of cars on the road, the importance of car accidents, and the wider cultures of car upgrade and customization (see Table 2).

Another form of auto repair organization also appeared early on in the history of automobility: mobile roadside repair groups. Most of these were set up early on in the history of the automobile, usually around motoring clubs. Again, the UK is a good example.[14] The Royal Automobile Club (RAC) was set up in 1897 using a translated and modified version of the constitution of the Automobile Club de France. It introduced uniformed motoring patrols in 1901 and roadside emergency telephone boxes in 1912. The Automobile Association (AA) was set up in 1905 and by 1908 had set up the *AA Member's Special Handbook*, a nationwide list of agents and

Table 2 Indicative data for the Motor Vehicles Repair Sector in Great Britain, 1995–2003

	Number of enterprises	*Total turnover (£ million)*	*Total employment (thousands)*
1995	17,060	8,900	–
1996	19,709	8,260	–
1997	22,027	8,011	–
1998	24,690	8,975	154
1999	26,089	11,118	159
2000	27,202	11,218	157
2001	27,862	11,890	164
2002	28,489	11,964	166
2003	29,229	12,060	176

Source: National Statistics, derived from Annual Business Enquiry Data (http://www.statistics.gov.uk/default.asp)

repairers. From the early 1920s, it introduced a system of pre-purchase and post-accident repair checks. Following the introduction of two-way radio, a night-time breakdown and recovery service was launched in 1949, initially only in London but then extending to the rest of the UK over time. In 1967, an insurance brokering service was introduced, heralding a move into financial services. In the 1990s, satellite technology was used to speed up response, while in 2003 all AA patrols were issued with laptop computers that could be plugged into the car's electronics to diagnose the cause of a breakdown.

At least to begin with, the RAC and AA tended to be the preserve of the relatively well-off who could afford cars – for example, by 1939 the AA membership had grown to 725,000, a number equivalent to 35 percent of all cars – but a substantial number of people had to fall back on self-repair.[15] Interestingly, in recent years both the RAC and the AA have been taken over by companies whose focus is the more general provision of utilities and finance and whose main skills might be thought to be in customer relationship management, logistics and financial services (signalling the early intersection between roadside breakdown and insurance).[16] Such associations point to the way in which maintenance and repair is increasingly thought of as a generic activity, the model for which can be spread across many realms of everyday life. In turn, other roadside breakdown companies have been formed, usually as part of a more general financial services initiative.

The second example is road repair. Roads continually wear out and need their surfaces patched and then replaced. Similarly, the utilities that lie under roads often need concerted intervention;[17] the growing construction of utilities caused by utility liberalization causes rapid growth in the incidence of city roadworks (Marvin and Slater, 1997). This constant business of road repair and maintenance is big business nowadays, a business that has a number of components: government (in the UK, the Department for Transport) and local authorities (some of which still have their own direct works departments in the UK), a few main contractors (in the UK, AMEC, Balfour Beatty, Carillion, Alfred McAlpine), and a host of smaller contractors which are often linked to the larger contractors in supply chain relationships. The stakes are large. Indicative figures from the UK reveal that, in 2000/2001, new construction, improvement and structural maintenance of trunk roads and motorways and their associated lighting systems absorbed over £1.1 billion and £241 million of state spending respectively. Local road maintenance and repair, meanwhile, absorbed just short of £2 billion, with associated maintenance of lighting systems costing another £1.3 billion (Regional Trends, 2000/2001).

Road repair and maintenance has many dimensions. Just two examples will suffice. One is potholes. Potholes are a contentious political issue, not least because insurers have increasingly blamed them for breakdown claims and are acting accordingly.[18] The other is a history of invention. Recently, road maintenance has involved considerable technical invention, from cold laid permanent repairs (which first became available in the 1970s), through the latest generation of low-noise road surfaces to new ways of filling potholes like Jetpatcher, as well as including a vast range of specialized repair equipment, such as road planers and pavers. This history of road construction and maintenance is only now being uncovered (see Merriman, 2005).

The final example is automobile accidents.[19] Automobile accidents are often personal catastrophes but they are normal facts of everyday urban life and, as if to illustrate this point, they are surrounded by a large and continuous infrastructure, from ambulances, fire services, hospitals and the car repairers just discussed, through police and motorway patrols to tow trucks and insurance assessors. They also involve a large range of skills, from forensic photography to the knowledge of how to run teams consisting of actors from many different emergency services. But this crash ecology has not come into existence overnight. It has been built up over a long period of time.

Conclusions: 'Surfacing Invisible Work'

This article has tried to argue that a major research challenge in the social sciences currently is to re-imagine economies and places in ways which, to adopt Susan Leigh-Star's term, manage to 'surface the invisible work' (1999: 385) of maintenance and repair that continuously surrounds infrastructural connection, movement and flow. Maintenance and repair is an ongoing process, but it can be designed in many different ways in order to produce many different outcomes and these outcomes can be more or less efficacious: there is, in other words, a *politics* of repair and maintenance. The politics of repair ranges through many issues and scales. These parallel the mobilities sustained by the configurations of 'infrastructure' that have been our concern in this article.

Increasingly, the politics of repair saturate wider geopolitical struggles and conflicts. When the possibilities of repair were withdrawn from the people of Iraq, for example, because UN sanctions made it impossible for their electrically powered water and sanitation systems to be brought back into good use after they were deliberately devastated during the 1991 Gulf War, it has been estimated that 111,000 Iraqi civilians died within the year of the preventable, water-borne diseases that resulted (Graham, 2005).

The politics of repair also emerges in a host of other arenas: the wages, conditions, locations and hours of repair work (many of the poorest people are concentrated in maintenance and repair jobs, like cleaning of various kinds); the politics of knowledge of repair (with the constant effort currently being made by many firms to deskill repairers and to transfer their knowledge into software; see Head, 2003; Henke, 2000); the concealment of the sheer expenditure on repair that is constantly found in the military–industrial complex; the proneness of certain systems to break down catastrophically, resulting in disaster and the need to apportion blame (Fortun, 2001); the uneven social and spatial provision of back-up and alternative systems; and the efforts by both state and non-state adversaries to deliberately work to disrupt, disable or destroy the networked infrastructures that sustain cities and societies (Graham, 2005).

A multiscaled environmental politics also surrounds repair and recycling. These provide a particularly powerful closing illustration of just how taken-for-granted infrastructures can be. Three issues seem particularly relevant here. First, many modern commodities are deliberately designed so that the possibilities of maintenance and repair are foreclosed (Verbeek, 2004). They lack any kind of transparency so that their functioning cannot be restored if they break down. This applies all the way from simple electrical plugs and power adapters, which are tightly sealed, to increasingly modular computer systems, through to motor car electronics, which can only be worked on in a specially equipped garage by mechanics who use diagnostic programs to slot in new circuit boards:

> . . . cars have become more reliable over the years and you don't have to change parts as often as you used to, but the downside is that when something does go wrong you can't fix it yourself and it will cost you a lot in a garage. (King, cited in Gadher, 2006)

Second, many increasingly sophisticated commodities are actually made to be replaced and disposed of through accelerating cycles of acquisition and almost immediate disposal. This results in obvious ecological problems to do with the generation, transportation and disposal or recycling of waste. Thus, in modern developed countries, most products are thrown away long before they have reached the end of their useful life, even though they could have been repaired. The average mobile phone in Western nations is now thrown away after only 11 months of use; the average lifespan of a computer in such countries had shrunk from 4–5 years in the 1990s to less than two years by 2005 (*JEM*, 2005). As a result of this latter trend, by early 2005, there were around 315 million obsolete PCs in storage around the world awaiting disposal or recycling (Barrington, 2005: 23). Thus, 'E-Waste' is the fastest growing segment of the overall waste stream. It produces its own (usually ignored) transnational geographies of repair and, increasingly, elemental recycling. A continuous and massive transfer is occurring of unwanted and often virtually new electronic equipment, which flows 'downhill on an economic path of least resistance', from the major cities of the global North to the processing spaces of Asia, Africa and Latin America (Shabi, 2002: 36). Most E-Waste is currently dumped 'offshore' in low-wage locations to be picked apart for precious and trace metals by tens of thousands of men, women and children, working in extremely dangerous conditions. For example, in the semi-urban area of Guiyu, in the Guandong province of China, over 1,000,000 men, women and children earn US $1.50 a day breaking up discarded servers, computers, mobiles and other electronic equipment by hand in order to extract valuable steel, aluminium, copper, manganese and gold.

Such deepening problems could be changed by fundamentally altering the nature of tool-being. Products could be designed so that they are easily maintained, repaired and upgraded, using light materials and structures and various forms of metering (Van Hinte and Beukers, 1998). Technological paradigms oriented towards the fetishistic generation of accelerating waves of quickly disposed of hard products could be reorganized around longer-term and sustainable systems of service delivery designed from the outset to be easily and continually upgraded. For example, Barrington (2005: 23), argues, in the case of IT industries, that 'PCs currently consume massive amounts of raw materials, drain huge amounts of energy, and have short life spans. . . . The IT community needs fundamentally to redesign IT around what it does (delivery) rather than what it is (technology).'[20]

Alternatively, repair and maintenance activities could be actively expanded, so that commodity production and waste were both minimized (Verbeek, 2004). Design consultancies like the Eternally Yours Foundation in the Netherlands (Eternally Yours, 2004), have already attempted to design products that would have a new and more knowing relationship to maintenance and repair.

Finally, much maintenance and repair itself generates the use of other secondary and often non-renewable products, and most notably paper. The business of maintenance and repair is a business that is still replete with large volumes of paper reports, alerts, archives, invoices, post-its and the like, which, even in the 'paperless office', computers have done little to allay and much to make worse.[21]

Such examples underline the fundamental point that this article is trying to make. Repair and maintenance are not incidental activities. In many ways, they are the engine room of modern economies and societies.

As such, they form a challenge to our ways of thinking about things which is more than just an expression of their supposedly passive and banal presence. For what we see is that repair and maintenance are vital parts of the relays of everyday life which involve their own forms of sending (Siegert, 1999). Without them, life would be impossible. Rather like the postal system, they form a minimal discourse of commands, dates, addresses, manuals, storage and feedback which whispers the world into existence.

Notes

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1. As Brown et al. (2004) show, Darwin did not get his descriptions of earthworm intelligence right, attributing powers to earthworms that subsequent research shows were exaggerated.

2. As Phillips points out, Darwin's description of the earthworm can be counted as his version of *The Making of the English Working Class*.

3. No doubt, we could have chosen another biological analogy – for example, the constant symbiotic work of bacteria (Margulis, 1998) – but this analogy will serve for now.

4. Remarkably, very few Heideggerian scholars have taken up this insight and made more of it. An exception is Harman (2002) who, in his heretical account of tool-being, concentrates matters on the broken, visible tool, arguing that all tools are encountered in their being as broken equipment. Significantly, he relates brokenness to space.

5. Thus, most infrastructural systems are made up of many different sub-systems dating from different times, with different records of reliability and different needs for repair and maintenance regimes.

6. One of the most serious problems currently is the way in which polymer cable casing wears out after about 20 years. This is a problem that affects homes and even aircraft.

7. Fire ants have proved a particular problem in Texas.

8. Notoriously, animals have been responsible for some of the major infrastructural events of recent years, providing a nice example of how the natural world acts as a constant hybrid intervention into technical systems. Notorious examples include the rats that severed telecommunications fibre on a bridge in the Rimutaka area of New Zealand's North Island in 2005 which, in concert with the parallel severing of a cable by a contractor, caused a major outage; the depredations of field mice in rural Sweden, causing major telecommunications network outages; and numerous squirrels becoming trapped in electricity substations. On one estimate, in New York 18 percent of all phone cable disruptions are caused by rats, although a more realistic estimate is probably AT&T's figure of 1 percent. More bizarrely, badgers were recently responsible for a collapse in the Llangollen Canal in Shropshire, while sharks have been known to bite through underwater cables (Brown and Bostrom, 2005).

9. For a particularly good illustration of this, see Ogborn's piece on archives and insects and Otter's piece on wooden pavements in Harrison et al. (2004).

10. Human error is one of the main reasons for breakdowns in infrastructural systems. Thus, the ubiquitous excavator is constantly slicing through cables and pipes and, when a repair is being made, it does it again to the back-up cable or other utility.

11. See Mokyr's (2001) comments on the importance of this kind of knowledge during the Industrial Revolution. The difference now is that such knowledge is much more easily consolidated through devices like the Internet.

12. The one exception we have been able to find is the work on contract window cleaning, mainly of commercial premises, that is undertaken by increasingly large multinational corporations using large cohorts of temporary staff (Allen and Pryke, 2004; Coe, 2005).

13. Indeed, most larger software systems now demand continuous upgrading, and the training cycles that go with it.

14. In North America, the American Automobile Association was launched in 1902, initially as a group of auto enthusiasts but becoming a national consortium of automobile clubs which offers reciprocal services, while the Canadian Automobile Association was launched in 1913.

15. Though we suspect that this is a dying art except among groups of enthusiasts. The AA currently has 15 million members in the UK, for example.

16. The RAC Motoring Service was taken over by in 1999 by Lex Service plc, has recently been acquired by Aviva and is being integrated into Norwich Union Insurance. The AA was demutualized and taken over by Centrica in 1999. In 2004 it was acquired by two European private equity firms: CVC and Permira.

17. The fact that so many utilities thread cables and pipes under roads means that they are particularly vulnerable to botched repairs by contractors.

18. By one estimate (from insurers keen to claim from local authorities), one in five breakdown claims in the UK are to do with poor road conditions (Sulalman, 2005).

19. For example, there were 207,410 road accidents resulting in personal injury in Great Britain in 2004, resulting in 280,840 casualties. Of these, 29,726 resulted in death or serious injury.

20. Intel is currently attempting to do this, based on redefining what it counts as progress.

21. Indeed, they may just have made things worse. One estimate (Thackara, 2005) suggests that computerization produces an eightfold increase in paper use. See also Sellen and Harper (2002).

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