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Intelligent mobility systems: Some socio-technical challenges and opportunities

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Abstract. Analysis of socio-technical challenges and opportunities around contemporary mobilities suggests new interpretations and visions for intelligent transport systems. Multiple forms of intelligence are required (but not easily compatible), transport is too narrow a term, and innovation results in new socio-technical systems. An exploration of cumulative, collective and collaborative aspects of mobility systems, allows us to sketch challenges and opportunities in relation to practices of collaboration, communication and coordination, literacies for creativity, comfort and control, citizenship and (lack of) a sense of crisis, concluding with a discussion of methodological implications.

Keywords: intelligent mobility systems, socio-technical, collaboration

… software will become as crucial to mobility as physical capacity …. [But] social practices will … adapt and/or appropriate particular socio-technical developments in complicated ways. (Dennis and Urry 2008, *After the car*. [1])

1 Introduction

There is more to intelligent transport systems (ITS) than system 'intelligence', transport and technology. Ubiquitous computing, connectivity and approaches to make computing 'autonomous', self-configuring and self-healing have great potential for new forms of mobility. However, realizing this potential is a matter of appropriation, not just design and implementation. What we mean here is that everyday users – from motor manufacturers, through public-private implementation partnerships, to service providers, security agencies, and individual travelers – play an important part in shaping new socio-technical mobility systems. How they utilize technology, cope with complexity, and invent new practices is unpredictable, yet vital to innovation. This human intelligence can make or break new mobility systems.

But human and system intelligence do not mesh easily, not least because travel and movement of goods and products are socially motivated and socially organized. People actually rarely 'transport' anything – they deliver, shop, dispose of waste, meet, visit, commute, travel. The practices involved are subject to ongoing 'everyday innovation'. Individualised time-space-speed rationalities often assumed by transport research are embedded in changing, dynamically coordinated social logics. For example, urban commuting patterns are defined not only by the fastest route from A to B (via C, D, E, including shops and schools), but also by dynamic 'micro-coordination' between friends and family using mobile phones [2], and more recently the use of GPS and locative media [3, 4]. Aesthetic, health and environmental considerations affect mobility behaviours [5], and people work, socialize, and relax while on the move [6]. Patterns of mobility are effects of lived social logics, complexly intertwined with economic, spatial and other calculable forms of logic.

In this paper we sketch out key challenges and opportunities that the sociality of mobility brings for the design of intelligent mobility systems. We focus on the cumulative, collective and collaborative nature of mobility systems to explore ideas for design approaches that support social practices of collaboration, communication and coordination, literacies for creativity, comfort and control, new senses and sensitivities of citizenship, and a constructive sense of crisis.

2 Cumulative, collective, collaborative

Many engineering and sociological perspectives look at phenomena of social order such as traffic from above. A bird's eye view is produced either literally, for example, through observation from a high vantage point [7] or figuratively, through modeling, simulation and mapping. Such detachment and abstraction seems useful not only because it makes general patterns visible, but also because it draws out multi-causal connections, for example between individual drivers' behaviours and cumulative phenomena such as traffic jams [8]. From often arduously achieved analytical vantage points, emergent phenomena can sometimes be explained by studying the interactions between relatively simple rules of individual behaviour. Social science can contribute to this explanatory effort and the design of intelligent mobility systems through specifying underlying rules, identifying types of individuals [9], as well as by developing theoretical models.

More recently, debates around the 'digital economy' have suggested that apart from 'mindlessly' cumulative (but potentially hugely consequential) emergent phenomena there are also more creative and constructive collective phenomena. An example of 'collective intelligence' [10] is the massive multi-player effort involved in the 2003 alternate reality game (ARG) 'We love bees' [11]. At its height, the ARG puzzle of a kidnapped beekeeper brought together more than 600,000 participants from across the globe. To solve the puzzle they used Web 2.0 Internet technologies and mobile phones to communicate, instantiating, according to Leadbeater, a novel form of collaboration: mass innovation. What is remarkable about this emerging form of collective sense-making and action is that it is 'not an anarchic free-for-all; it was organized, but without a division of labour imposed from on high'. New mobility service models such as car clubs, lift share or lets schemes build on and develop such practices and are extending more conventionally conceived ideas of ITS [12].

We appreciate these contributions and their relevance to developing new intelligent mobility systems and services. However, mobile methods of research – for example ethnographic participant observation with mobile workers [13] and experimental implementations of prototype technologies in technology design and art [5, 14, 3] – place researchers in amongst drivers, pedestrians, players. Changing perspective like this raises critical new questions: How do participants on the ground understand, orient and contribute to the orderliness of mobile societies [Garfinkel, in 15]? They do not have a view from above, so order must manifest on the ground as well. How? What is the relationship between order on the ground and order as seen from above? What implications does the fact that order is made in motion have for the design of intelligent mobility systems? These are complex questions that go to the heart of our understanding of sociality, technology, and mobility. In research on human-computer interaction, computer supported cooperative work and participatory design, questions like these have given rise to a powerful concept of 'situated action' and design approaches that seek to support its operation [16]. Actions are situated in the sense that they are contingent, negotiated in communication and collaboration with others, and in interaction with environments, material artefacts and technologies. Studies show that plans, rules, models, theories are important resources for, but not sufficient descriptions of, situated action. Drawing on this work, we can highlight key aspects of the sociality of mobility 'on the ground'. After presenting these as a cluster, we will draw out challenges and opportunities for designers of new mobility systems.

Key aspects of the sociality of mobilities on the ground:

- *Scenic intelligibility*. People can often tell what other people are doing or are going to do by looking. Recognition of, and the ability to fit into, social scenes – for example, different cultures of driving when travelling – are practical, sequentially, spatially organised achievements [17]. For instance, by observing a car's orientation to other cars, drivers can make remarkably precise judgments about the 'kind of person' another driver is, whether they are planning to overtake, are attentive or tired, amicable or aggressive [15]. Social relations are, so to speak, made in the gaps between vehicles [15], documenting creative contextual reasoning rather than simple rule following behaviour.
- *Accountability*. Scenic intelligibility relies on the fact that actions (and, to a degree, intentions, motivations, emotions) are 'account-able', that is, observable and reportable [18] – not just retrospectively to determine culpability for failures, but also in real time through embodied conduct, which (sometimes involuntarily) accounts for what people are doing, thinking, intending to do (see also [19]). Studying behaviour in public places, for example, Goffman describes how pedestrians 'diagnose' opportunities for passage between lone walkers and parties, identifying 'vehicular units' [20], 'whose coordinated gait accountably achieves their ''togethering''' [21]. Technologically augmented 'embodied' conduct (with e.g. spoilers, indicators, engine sound) allows the subtly meaningful negotiation of proximity, speed and orientation.
- *Phenomenal field*. Accountability in environments designed for mobility and inhabited in motion, also has an experiential dimension. For example, people experience speed not only by looking at their in-car instruments, but also through sensing their own movement and other vehicular units' speeds. The resulting negotiation locally defines 'normal speed' – often in line with official limits, but also open to drift, depending on perceived safety and circumstance. Today the world 'mediated by technology is known in no less immediate a fashion than is any other experiential life world' [15], and the resulting 'phenomenal field' is an intersubjective field, that is, it is experienced as

sufficiently the same for everyone (allowing for cultural, biographical, or physiological differences), where principles of reciprocity of perspective and experience apply [22]. Reciprocity means that if I changed place with you, I would see what you see and experience what you experience. These principles matter enormously in the actively produced order of mobility on the ground, because they make others' behaviour intelligible, predictable, anticipatable.

- *Indexicality*. Actions are 'indexed' by and meaningful in relation to context. For example, a slow driver turning on his left indicator on a wider stretch of a narrow road with no turn-offs is likely to be inviting cars stacked up behind him to pass, rather than indicating that he will turn left at the next turn. A flash of left-right-left indicator lights by a passing driver can be read as a 'thank you' in response, rather than an emergency warning or a confusion over where to turn. Indexicality is an immensely powerful resource for creating order on the ground.
- *Reflexivity*. Action is made meaningful prospectively and retrospectively, shaping context as it unfolds. For example, a glance in the rear mirror may reveal the driver left behind above waving and shouting, revealing the indicator signal to have actually been meant as a request for help. Retrospectively, it defines the context of the situation as troublesome rather than easy, revealing 'context' to be a fluid effect of action rather than a fixed 'container' for action

Against this backdrop, mobilities emerge as locally organized, practical, collaborative achievements. They are ordered, but through contingent, embodied and emplaced situated reasoning and action rather than rule following and internalized cultural consensus. This explains how traffic can remain (relatively) orderly even when people do not follow rules or when unforeseen events occur, and it illuminates how unspoken cultural traffic conventions in different countries can be intelligible (enough) for safe driving. Indeed it highlights how traffic is in important and constructive ways as much a matter of 'making it up as we go along' as it is of following rules. From this appreciation, two key challenges/opportunities arise.

Intelligent mobility systems: key challenges/opportunities

Firstly, designers need to move from a concept of rule governed behaviour to an appreciation of contingent social and material practices of creating order on the ground, and a notion of mobility rather than transport systems. The user profile currently inscribed in ITS technology (individual, rational, planning) and a unit to be 'transported' is inadequate. Rather than just being concerned with getting to and from locations, people (as well as goods and products) are mobilized in and through situated action. Everyday practices intersect so intricately with technologies, material environments and artefacts as to come together as socio-technical systems of mobility. Such a move is challenging, not least because of the complexity it introduces. However, shifting the focus from transport to mobilities also highlights powerful opportunities for design to support social and material practices and intersections between different forms and modes of mobility, most significantly the convergence of physical and virtual mobilities brought about through growing use of the Internet, mobile phones and locative media, also when on the move.

Secondly, in view of the varied manifestations of human intelligence in mobility systems, it is fruitful to move from a focus on computational 'intelligence' to approaches that support and integrate multiple intelligences. These should include:

- *Situated human sense-making practices*: drawing on approaches of augmenting human intellect [23], we call for approaches that support people in managing the scenic and phenomenological intelligibility of mobile societies.
- (*More extrovert) system reasoning*: given the complexity of future mobility systems, automation, context awareness, and self-configuration are critical tools. However, these forms of system intelligence need to be designed in a way that supports alignment with human intelligence [24].
- *Intelligence production*: the efficiency and flexibility of intelligent mobility systems depends on rich, live information. Automatic sensing and data collection is useful, but not enough because there can never be enough data, it is hard to know what to sense, sensors fail, and many activities cannot easily be sensed by machine sensors. Moreover, the cost of installation/commissioning of distributed ad hoc sensing is high.
- *'Global' sense making or qualculation*: The concept of 'qualculation' [47] describes the combination of calculation and qualitative judgement enabled by sensing technologies, data collection and computation. It builds on the actuarial calculations undertaken by insurance and marketing companies and their representational practices to make sense of phenomena that are 'too far, too small, too fast, or too slow, or even too big to be experienced by us as we are presently constituted' [25]. With Thrift, we argue that socio-technical innovation opens up possibilities to 'constitute ourselves' differently. In other words, we argue that people can acquire new sensitivities, sensibilities and practices that allow them to sense and make sense of cumulative and collective phenomena.

We now begin to develop these ideas through discussion of collaboration, communication, coordination, literacies for creativity, comfort and control, new senses and sensitivities of citizenship, and a constructive sense of crisis.

3 Collaboration, communication, coordination

Collaboration, communication and coordination are becoming increasingly important as products, goods and people are becoming more mobile. Practices of micro-coordination between people could be better supported by providing more, more reliable, accurate, real time, and credible information for people to plan, manage and coordinate their journeys. The main challenge in informed travel is to identify the right balance between intelligence provided by the infrastructure and the volume and form of information delivered to travelers, in order to allow intelligent decisions.

Existing travel information systems, such as electronic signage on motorways, are designed to consider travelers as crowds, lacking personalised information, format and delivery. Moreover, most advanced traffic management systems rely on a centrally controlled infrastructure and information source. These two characteristics hinder the development of trust and credibility in such systems. Indeed, a travel information system that delivers information unrelated to someone's journey, gradually becomes 'noise' for the traveler. As shown by Foo and Abdulhai [26] the reaction of drivers to electronic signage messages decreases over time, showing a potential distrust of the displayed messages. An information system that relies on a single source of information (for example the Highway Agency is the primary source for reporting congestions or accidents in the UK) is at risk of becoming untrustworthy. Incidents where wrong or inaccurate information is delivered by the single information source, would damage trust levels on the system as a whole.

An opportunity is to consider recent trends in mobile computing, for example, context-aware applications and participatory sensing, along with trends in internet technology, for instance, user generated content and social networking applications. Location based applications are the most common examples of context-aware applications [27] but context aware systems may also include attributes such as user preferences, time or proximity of other users to adapt their behaviour [28]. The concept of participatory sensing is a more recent phenomenon and describes systems in which users actively participate in a project as 'sensors' [29]. Moreover, by visualizing the connection between the measurements and the measurers, a sense of community can be supported, as illustrated in *comob*, a mobile phone application developed by two locative media artists to map spatial relationships between family, friends, or community sensing groups [30]. Web 2.0 technologies such as social networking sites and user generated content allows information to be shared among users in a reliable manner. In particular, social dynamics that operate in many on-line communities and content sharing sites have been shown both to scale to very large numbers and to ensure users are able to develop appropriate internal trust practices.

Cost-savings are an important incentive; it costs road network operators to plan/commision/de-commision sensors on the road while it is relatively cheap to have sensors in cars and mobile devices. Further, higher precision/granularity of information can be achieved from distributed sensing. But the combination of such technologies also has the potential to allow the design of real-time travel information systems that are built around relationships between people. For example: "if particular travel information is provided by my colleagues I will trust it'. Moreover, as we will discuss further below, by turning individual users into a source of information, designers can develop more flexible models for privacy control: 'I will share my location with my family, and, when arranging a meeting, with my colleagues'. Aggregation of information on a community level can help develop a constructive sense of crisis (see below): 'What is the carbon footprint of my neighborhood?'.

Primary challenges for context awareness and participatory community sensing are the development of mechanisms to collect and deliver the right information in the right context. Intelligence lies in the discovery of each person's context and the correct filtering and presentation of the delivered information.

Literacies of mobility: Creativity, comfort and control

Creativity, comfort and control are perhaps the most important aspects of contemporary mobility systems, which are built around fossil fueled, steel bodied, individually owned and predominantly individually used cars and lorries [1]. Creativity, comfort and control have many different aspects, reaching from the cultural creativity in expressing status and individuality through car ownership, to discourses of safety, privacy and cocooning comfort, and notions of flexibility and control over one's destinations on the open road. In this paper, we focus on one particular aspect that cuts across creativity, comfort and control: embodied literacies of mobility. How do people probe, explore, perceive, make sense of technologies of mobility? How do they find their bearings amongst them? How does this allow them to be creative, make themselves comfortable, put themselves in control? How can technology design support attempts to develop literacies and find one's bearings? By specifying challenges/opportunities and design initiatives that arise at this juncture, we can concretize and develop our suggestions for design.

Mark Weiser's pioneering vision for 'ubiquitous' computing [31] has been extremely powerful in this regard. Its 'highest ideal to make a computer so imbedded, so fitting, so natural, that we use it without even thinking about it' and Weiser's call to make the computer 'invisible' have been enthusiastically embraced by technology designers, most often literally. For all the right reasons – for example, to protect car drivers from complexity overload – designers seek to hide computing by embedding it in devices and environments, making it 'autonomous', self-healing, and context-aware [28]. These approaches can be powerful, but they can also – paradoxically – impede what they seek to support by undermining principles of intersubjectivity and reciprocity as well as practices of making sense of the phenomenal field. For example, if speed is sometimes, for some drivers controlled automatically (e.g. through proximity sensing), practices of negotiating embodied accountabilities are disrupted. But Weiser's main concern was not invisibility per se, but 'invisibility-in-use', synonymous with the phenomenological notion of 'ready-to-hand' [32], meaning that users should be able to focus on their activities rather than on their technologies.

To achieve 'invisibility-in-use', it is becoming increasingly clear that approaches to design more 'extrovert' forms of system reasoning that support situated sense-making practices rather than black-box function are required, echoing early calls for computer-based coaching to enable computer users to 'diagnose' machine capabilities [33]. Bellotti et al [24], for example, highlight the challenges of 'making sense of sensing systems'. Drawing inspiration from analyses of situated interaction between people, they focus on problems of addressing embedded systems, mutual attention and alignment, noticing and addressing accidents, and they seek to sensitise designers to the challenges of human-computer interaction. In a similar vein, drawing directly on Weiser's work, Chalmers [34] proposes 'seamful design', revealing system 'sutures' (for example, between areas where location information is or is not available), and Dourish [35] calls for 'accountable' computing:

> Accountability, in this sense, means that the interface is designed so as to present, as part of its action, an "account" of what is happening. The goal of the account is to make the action of the system concrete as part of an ongoing interaction between the system and the user. So, the account should not simply be an abstract description of the system's behavior, but rather an explication …

However, not surprisingly, given situated sociality of mobility practices discussed above, accountability in this sense is exceedingly hard to design 'into' intelligent mobility technologies. Anderson et al [36] articulate how autonomy undermines the little 'natural' accountability that computing systems have (by way of deterministic behaviours). Most notably they argue that appropriate or 'recipient designed' accounts (accounts that are sensitive to recipients' indiosyncracies and context) are required to 'explicate' in ways that are relevant and understandable in specific use situations. This is impossible in encounters of man and machine, where asymmetries of sentience place technology at a disadvantage in the reflexive production of recipient designed moves [33]. Anderson et al appreciate this difficulty and recommend participatory engagement with prospective end users, because this will give designers at least an idea of the kinds of accounts that would be required and in what kinds of situations.

We build on this research, but, given the inherent difficulties of understanding function from the design of interfaces, and of designing appropriate accounts, we shy away from notions of human-computer 'interaction' and 'accountable' computing, and a focus on interface design. Instead, we study the 'diagnostic' methods of how people make material artefacts, environments and technologies within their phenomenal fields 'speak', how they notice, act in line with, and create order in human-technology engagement. We describe this as supporting people in making computing 'palpable' [36]. Such diagnostic practices are critical to people's ability of finding their bearings or moorings, act creatively, and find comfort and control [37].

Citizenship

Sharing of mobility-related data and experiences, automatically sensed or manually contributed in social networks opens opportunities for intelligent mobility systems, leveraging users as intelligent sensors. At the same time, concerns that already exist regarding the storage, processing and dissemination of personal information in social networks become amplified by the increasing inclusion of detailed movement data. Users may willingly grant operators almost unlimited use of mobility pattern data, in exchange for the benefit of enhancing their social and their mobility experience. For example, while the use of locative media clearly has the potential to accidentally share information with someone, it is the automated categorization that poses the biggest threat. Beresford and Stajano [38] have shown how even anonymous traces can yield the identity of users when combined with profile information. Krumm [39] analysed GPS data from 172 drivers and was able to infer a home address in 13% of all cases, and names in 5%. Bettini, Wang and Jajodia [40] have thus argued that location history can act as a quasi-identifier of users. One of the key challenges of creating desirable intelligent mobility systems is the fact that by making the mapping, tracking, interrogating of movement in physical and digital spaces possible, we not only enable 'intelligent' mobility behaviour, but also enable large scale, potentially intrusive surveillance. This could erode civil liberties and people's privacy.

Clearly, this threat should be addressed and some promising approaches are emerging. Many technical approaches to preserve location privacy have been proposed - from separation of who from where and when in mobility data (e.g., k-anonymity, [41]), to obfuscation by blurring detail in the data [42]. However these approaches generally assume a dichotomy in the use of location data, as either authorized or unauthorized. The act of sharing mobility-related data is then reduced to a binary decision: friends are granted access, strangers are blocked. Yet, privacy is not just about anonymisation or confidentiality, it is a "boundary negotiation process" (Altman, in [43]). Dourish, whose call for 'accountable' computing pioneered the use of computational reflection to support human-computer interaction is exploring how it might support people in understanding privacy [44] in pervasive computing.

An important challenge is to understand sharing practices for mobility-related data, and to develop usable technologies that support the negotiation of privacy. Social science studies are beginning to address these questions, examining how people are developing new sensitivities and senses in engagement with new mobile technologies, and new social practices of managing privacy of their digitally augmented mobile bodies more effectively. Licoppe [45], for example, describes emergent practices of managing co-proximity in his observations of a community of mobile game players in Japan, where users tried to manage the implications of being tracked and thus visible to unknown fellow players. People would go to great lengths to acknowledge the possibility of face-to-face meetings when two players happened to be close, but also employed elaborate excuses for why such meetings could not happen. Design, policy and practice should engage with such studies and support such emergent practices.

A sense of crisis?

Cumulative or collective effects of situated action within mobility systems (such as congestion, air pollution and climate change) are ill understood by those causing them, and only partially understood by those studying them. This makes it difficult to change practices and design strategies, policies, technologies, infrastructures to bring about desirable effects and avoid or mitigate undesirable ones. A key problem in moving intelligent mobility systems forward is the fact that with creeping troubles such as congestion, air pollution or climate change, people often struggle to establish a sense of crisis until it is too late, which can also be seen in histories of environmental crises [46]. Thus, not only can we never know enough to reliably 'engineer' new socio-technical mobility systems, but without a constructive sense of crisis, we also lack motivation. Without a sense of crisis (and a sense of the possibility of constructive action) acceptance and investment in intelligent mobility system technology and behaviour change will be too patchy to make the 'critical mass' needed for a working intelligent mobility systems. The rejection of the 2008 Transport Innovation Fund application in Manchester is a potent example.

Community sensing that combines quantitative with qualitative located data and data analysis through 'qualculation' [47] promises some leverage here. Approaches such as the comob collaborative measuring initiative, or Christian Nold's urban emotion maps [see 30] resonate powerfully with ideas of 'reality mining', coined by Eagle et al [48], who carried out the largest experiment to date on machine learning from mobile phone data. A key challenge for research and socio-technical innovation is to move beyond people as data collectors, to people collectively making sense of data that is 'reality-mined'. For example, providing home energy data could be used not just so that energy supplies can be improved in some way, but so that personal energy-consuming practices can be understood/reflected upon in the context of consumption at many layers, from family to friends to community. With a view to mobility systems, social positioning methods used to study people's movements by tracking their mobile phones could inform not only planning decisions [49], but also everyday micro-coordination of mobility.

Discussion and methodological considerations

In this paper our aim was to sketch out key socio-technical challenges and opportunities for designing intelligent mobility systems and to motivate and enable designers to work with, rather than against, situated reasoning and everyday creativity. Mobility systems are nested socio-technical systems, with often contradictory forces at work, positive and negative feedback, and ripple effects for every attempt to constrain or enable collaboration, creativity, comfort or control, citizenship and sense-making practices. A key challenge is to juggle these forces and effects. This cannot be done through conventional 'design and implement' approaches. Iterative, collaborative design, using a 'living laboratory' approach [50] enables experimental appropriation or 'colonization' and shaping of prototype mobility systems. However, in the context of mobility, particular challenges arise: of engaging diverse stakeholder communities and large numbers of members of the public in such design endeavours. A closer look at playful collaborations can inform methods of engagement that address these challenges.

Leadbeater's analysis of the ARG 'We love bees' is inspiring for design, but somewhat superficial. He appreciates the work of the game's designers in creating the incentives and conditions for collaboration, but mainly celebrates the creative power of spontaneously self-organised mass innovation. However, on closer inspection, the relationship between the design (and the designers) of the game and the players is more complex and revealing for the design of new intelligent mobility systems technologies and services. McGonigal, one of the game's designers, reports how the collaboration between the players was very carefully orchestrated by a group of meta-players or 'puppet-masters', who strategically instructed and informed participants [51]. But far from being all-powerful masters, the puppetmasters were drawn into engaging encounters with their players. McGonigal describes the art of playing with players 'without making them feel like mere puppets'. It was not a matter of puppetmasters' pulling people's strings: 'we could give the players a set of instructions—but clearly we could not predict or dictate how they would read and embody those instructions. We were absolutely not in control of our players' creative instincts'. She also asks 'How do you develop the puppet master-player relationship into a collaborative one, and what real-time recourses do you have to actively manage that relationship?' and describes her team's strategies. Drawing inspiration from this approach, we would like to argue that 'living laboratories' for intelligent mobility systems may not just be understood as a means to the end of designing more effective intelligent mobility systems. They may actually describe a permanent state of socio-technical innovation that places an emphasis on the process of collaborative design and accepts that any resulting systems will be temporary and subject to everyday innovation in a way that should be supported as well as guided.

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