# Re-Programming Mobility Literature Review

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*About the Re-Programming Mobility Project:*

*Re-Programming Mobility* is a year-long series of investigations conducted by the Rudin Center into the far-reaching impacts of new information technologies on mobility, land use, and transportation planning. The project is supported by a research grant from the Rockefeller Foundation.

**Abstract**

This paper addresses questions of how planners and other transportation professionals should be thinking about, planning for, and managing ICTs. The review draws on existing literatures from urban planning, social and applied science, and the technological press. Key considerations include the history of technologies in transportation planning, theories explaining effects of technologies on travel, how planners deal with technologies today, and ongoing gaps in knowledge, concepts, and practice. This exploration is wide-ranging, as the range of technologies now transforming mobility is itself broad. I argue that in many cases planners are not yet prepared for the onslaught of ICTs and their effects on mobility. Even where researchers have begun to frame potential impacts, clear linkages to planning and have yet to solidify. Historically, technological advances have been a boon for travel, making systems safer and more useful, but also facilitating increased driving with its ancillary impacts. Conceptually, ICTs don't just reduce monetary and time costs, but also shift the patterns of daily life and fundamentally alter how people make choices about where to go and how to get there. These functional and psycho-social effects will continue to impact planners' ability to meet fundamental transportation planning objectives such as increasing accessibility, equity, sustainability, and livability. The potential for significant shifts in behavior suggests that dealing with ICTs is not just a matter of updated regulation, but of reconsidering longstanding assumptions built into the planning process.

## 1 Introduction / Key Questions

Planners are just beginning to grapple with the rapid expansion of information and communication technologies (ICTs), as well as other technologies that may impact cities and urban life. Transportation systems, particularly, are being transformed: app-reliant transportation network companies (TNCs) have undercut regulated taxi providers (Goldwyn, 2014), traffic data is crowdsourced rather than collected by governments (Silva et al., 2013), transit providers make their systems more usable and reliable with online wayfinding and tweets to and from users (Kaufman, 2012b), and the arrival of autonomous vehicles tantalizes, though well-founded skepticism persists (Hirsch, 2014). Broadly, these mobility-enhancing technologies include personal ICTs such as cellphones and smartphones, mobile apps, social networks, online search, and personal navigation systems, as well as similar computing and communications-intensive technologies such as self-driving cars and advanced traffic signals. While transportation planners are increasingly cognizant of technology's effects on mobility, the relationship between planners and the new technologies remains uneven and often ad-hoc. In order to successfully plan for and successfully leverage ICTs to meet longstanding objectives, transportation planners need a better sense of their role in urban mobility, conceptual frameworks for anticipating their effects, as well as a sense of the pervasiveness and diversity of the technologies with which they should be concerned. I argue that while planners possess tools and frameworks for addressing some aspects of ICTs, we are poorly equipped to deal with other aspects.

This paper seeks to address the broad question of how planners and other transportation professionals should be thinking about, planning for, and managing ICTs. To answer this question, I draw on existing literatures from urban planning, social and applied science, and the technological press. Key considerations include:

1) *The history of technologies in transportation planning*
2) *Theories explaining effects of technologies on travel*
3) *How planners deal with technologies today*
4) *Ongoing gaps in knowledge, concepts, and practice*

This exploration is wide-ranging, as the range of technologies now transforming mobility is itself broad. It would not be possible, nor effective, to synthesize the entire set of literatures relevant to the topic of planning for technological change in transportation. Instead, this paper takes the approach of highlighting key works and findings, organized in a structure that emphasizes the breadth of knowledge relevant to the issue.

In this paper, I argue that in many cases planners are not yet prepared for the onslaught of ICTs and their effects on mobility. Even where researchers have begun to frame potential impacts, clear linkages to planning and have yet to solidify (Cohen, Salomon, & Nijkamp, 2002). Historically, technological advances have been a boon for travel, making systems safer and more useful, but also facilitating increased driving with its ancillary impacts. Conceptually, ICTs don't just reduce monetary and time costs, but also shift the patterns of daily life and fundamentally alter how people make choices about where to go and how to get there. These functional and psycho-social effects will continue to impact planners' ability to meet fundamental transportation planning objectives such as increasing accessibility, equity, sustainability, and livability. The potential for significant shifts in behavior suggests that dealing with ICTs is not just a matter of updated regulation, but of reconsidering longstanding assumptions built into the planning process.

## 2 A *Very* Brief History of Technology and Mobility

The historic perspective allows planners to place new technologies within a continuum. Within that continuum some technologies may best be understood as incremental change, and others represent truly significant transformations of prior means of travel. Today the pace at which new technologies are being introduced is indeed rapid, but technological change in transportation is not a new phenomenon. New technologies, whether related to infrastructure, vehicle operation, or information provision, have always played a critical role in travel and the operation of transportation systems. Transportation historians have thoroughly documented how vehicle technologies that have increased personal mobility at lower costs has consistently led to additional personal travel and concomitant changes in urban land use and development patterns (Bruegmann, 2006; Muller, 2004; Wachs, 1984). The role of ICTs in transportation history, however, are less well known but also deserve consideration.

### *2.1 Transportation technologies and urban form*

Transportation, its vehicles and infrastructures, are themselves technologies, instrumental in reshaping cities and daily life. One of the most important narratives in transportation history is that of new transportation technologies reshaping urban form. While this narrative is well documented, it should remain central as we ask what effect new transportation technologies will have on urban form, and how planners may, or may not, play a role in this process.

#### 2.1.1 Technological advances and increasing mobility

Muller (2004) documents that transportation technologies have resulted in increase travel, as well as growth in the extend of urban settlements throughout history. As humans have moved from walking, to horse-drawn mobility, to mass transit, and then increasing automobility, individuals have been able to travel ever longer distances and cities have grown in concert. Vehicular technology is not the only part of this history. Infrastructure plays a major role. Muller and others makes a distinction between eras of "recreational" automobile use before World War II and postwar freeway-based mobility, where the advent of freeways resulted in ever more daily driving and suburbanization (Brown, Morris, & Taylor, 2009; Muller, 2004).

The history of road signalization fits within this larger history as well. Orderly management of roads has been a critical component of transportation management, and engineers introduced signals to increase the efficiency of existing roads (Mueller, 1970). Even as innovations in vehicle technology slowed during the latter half of the 20th century, innovations in signalization continued, with the introduction of advanced traffic control systems such as the City of Los Angeles' Automated Traffic Surveillance and Control (ATSAC) program (Rowe, 1991). Again, technological advances facilitated increased travel, reducing congestion but also arguably leading to induced demand and increasing VMT. Similar developments in rail signalization play a role in increasing safety as well as capacity both for passenger and freight systems (Zador, Stein, Shapiro, & Tarnoff, 1985).

### 2.1.2 The role of the planner

Importantly, though the history of transportation technologies is well documented, the role of the planner, and how planning may or may not have shaped technological adoption and operations, more debated (Taylor, 2000; Wachs, 1984). Histories that omit planners', as well as other urban actors, roles can evince a tendency towards technological determinism by not recognizing the role of policy and regulation. While new technologies were necessary for new levels of mobility and reorganization of the city, they are not sufficient to explain these changes. One key consideration is the difference in management of automobiles in Europe and North America, two relatively wealthy, industrialized regions at the advent of the automobile (Muller, 2004). Automobiles were and continue to be more restricted through pricing, regulation, and land use planning in the European context compared to the United States and Canada, so that despite historic growth in VMT in both places, rates of growth have been far slower in Europe. For a more specific case, Foster (1975) highlights the story of planners in Los Angeles, who largely embraced automobility in order to keep downtown Los Angeles competitive with suburbs and retain relevance in a car-focused political and social context. In general, the literature shows that planners and government have had always played a role in regulating and managing adoption and use of the new transportation technologies, but no examples exist of a technology being wholly unpermitted once feasible implementation was possible.

## *2.2 ICTs and transportation*

Information and communication have always been critical to the operation and usability of transportation systems, and include both publicly- and privately-operated ICT systems.

### 2.2.1 Public communications

Transportation planners have consistently sought to provide travelers with better information, in real time or near real time, using signage and media. What are now called Advanced Traveler Information Systems (ATIS) started with variable roadside signage and traffic reports on radio and then on TV (Chorus, Molin, & Van Wee, 2006; Khattak, Pan, Williams, Rouphail, & Fan, 2008). A traveler survey in Seattle in the late 1980s found that such systems already had a significant impact of travel behavior, with the majority of travelers willing to shift some aspect of their behavior, whether trip time, route, or even mode (Barfield, Haselkorn, Spyridakis, & Conquest, 1991) ATIS has only continued to develop and evolve from these early examples.

### 2.2.2 Interpersonal telecommunications

Mobile communications did not appear instantaneously in the late 1980s (Townsend, 2000). In fact, mobile telephones were first available in the United States in 1946 in a select number of cities. Immediately, these limited services were popular with logistics firms. While transportation planners had little cognizance of this limited role, as cellular technology was deployed starting in the 1980s, dividing the city into "cells" of signal reception, proliferation of towers has led to significant land use planning concerns, as neighborhoods have wrestled with mobile telephony companies over the density of towers and placement (Hughes, 1997).

#### 2.2.3 Maps and navigation

While the use of GPS and internet-based navigation has become widespread, the evolution of navigation is worth consideration. Specifically, humans have relied on their internal sense of direction and knowledge, gained through experience, of locations and routes between them. This spatial information is stored in the brain, inside the cognitive map (Downs & Stea, 1973). However, as transportation systems have grown more complex, people have relied increasingly on external navigation aids. For much of history, the main form of navigational assistance was the paper map (Guo, 2011). Particularly for public transportation systems, agencies have spent significant effort developing optimal maps to maximize system legibility and usability. Traditional transit maps have been highly schematized in their design, whether the classic London Underground map designed by Harry Beck, or multiple iterations of New York City subway maps, including the aesthetic but arguably unusable version by Massimo Vignelli. Guo has found that these maps matter, and distortions in maps relative to physical system layouts cause people to at times choose inefficient routes and transfers (Guo, 2011).

### *2.3 History and expectations for the future*

Another important lesson of history is that reality rarely matches expectations, and expectations of ICTs impacts on transportation are no different. Geels and Smit (2000) highlight three distinct eras in which nascent ICTs were argued to be potentially transformative, yet did not meet their potential. In the 1930s, automated vehicles were seen as being around the corner. In the 1960s and 1970s, computers and telematics were expected to significantly enhance road capacity. Finally, in the 1980s and 1990s, telecommuting was seen as a way to significantly reduce driving. None of these changes occurred to the extent or within the time frame expected – though we now believe many of these innovations are imminent, perhaps incorrectly.

## 3 Conceptual Frameworks and Theories of Technology and Travel

Beyond historic precedents, transportation and social science researchers have already established multiple frameworks for considering the impacts of technology on transportation. Some approaches engage directly with planners' longstanding concern for vehicle travel, while other approaches address potential social and behavioral transformation less commonly considered within transportation planning.

### *3.1 Potential relationships between ICTs and travel*

Over the past twenty or more years, researchers have begun the process of anticipating what impacts we might expect from this new wave of information technologies (Mason & Deakin, 2001; Moss, Kaufman, & Townsend, 2006). Mokhtarian and Salomon (2002) provide a basic framework for thinking about the relationship between telecommuting and travel. This framework can apply not just to telecommuting per se, but most types of ICTs. The four possible relationships they posit are:

- Substitution – ICTs replace and reduce travel;
- Complementarity – ICTs generate to additional travel;

- Modification – ICTs change the nature of travel in some way, such as its timing or purpose; and
- Neutrality – ICTs have no effect on travel

These relationships can be considered both in terms of the aggregate effects of ICTs on travel measured broadly, or in focused terms, estimating specific impacts of a particular technology on a specific type of travel. Thus, it may be that some types of online and mobile communications *complement* long-distance work travel, while they *substitute* for daily commutes, yet their overall impacts on VMT are *neutral*.

Aguiléra et al. (2012) highlight that the debate in the literature has thus far often crystalized around a dispute over whether ICTs are complementary or even generative of physical travel, or they can function as a substitution for travel. They note that the weight of the evidence so far suggests that ICTs are complementary or generative overall, though many issues remain to be investigated (Gaspar & Glaeser, 1998). They highlight that ICTs facilitate new ways of organizing the day, more extensive social networks, and even the experience of places and travel (Townsend, 2000). The need for face-to-face interaction to "seal deals" and consummate business and social relationships initiated online suggests that complimentarity between ICTs and travel is a reasonable claim (Storper & Venables, 2004).

Banister and Stead point out that ICTs will not necessarily reduce travel, even if telecommuting expands (2004). In fact, they suggest that the information provided by ICTs may provide people with new options for activities that replace any gains from more efficient or eliminated trips. Despite these studies, Aguiléra et al. (2012) describe the question of how ICTs will effect travel behavior as "futile." They recommend, however, that research focus on not just trip counts, but the "nature of travel demand." In particular, they emphasize the need for research on how ICTs influence social networks and reorganize activity patterns, phenomena rarely addressed in transportation planning.

Golob and Regan (2001) focus on specific types of ICT-driven behaviors, and identify potential impacts of information technologies on personal travel behavior based on the particular ICT. The types of ICT-driven behaviors are:

> "(1) online shopping (consumer e-commerce), (2) other online services, especially telemedicine, (3) flexible working arrangements, including telecommuting (or teleworking), (4) self-employment, (5) contingent and part-time working arrangements, (6) mobile working, and (7) education" (Golob & Regan, 2001, p. 96).

This list from more than a decade ago is remains remarkably consistent with today's reality. Golob and Regan speculate that the flexibility afforded by ICTs will facilitate changes in tripmaking, though the precise impacts are not clear. Importantly, they note that e-commerce may impact local commercial areas, largely to their detriment. The key role of e-commerce is reinforced by other authors, possibly reducing the need for shopping trips (Dijst, 2004; Viswanathan & Goulias, 2001).

### *3.2 Beyond the Debate over Complimentarity*

A concern with travel intensities, particularly vehicular travel (or other polluting modes such as air travel), is fundamental to the objectives of most transportation planners, who seek to improve access while minimizing impacts. However, planners' concern for ICTs need not be limited to measures of VMT or trip counts. Janelle and

Gillespie discuss issues which planners and policymakers must address to ensure that ICTs contribute to sustainable and equitable urban travel (2004). They argue that:

> "…[Planners] must devise means to protect and respect individual autonomy over personal information and behaviour; to protect and respect a minimum basic economic and cultural autonomy for places, regions, and nations; and to protect vulnerable environments and population from destructive uses and impacts of space-adjusting technologies" (Janelle & Gillespie, 2004, pp. 673-674).

Thus, they view ICTs as having distinctively new types of negative impacts, such as lost privacy, as well as the impacts of any "space-adjusting" technology such as impacts on localities and environmental impacts.

Malecki (2014) emphasizes that technologies, even disruptive technologies, function within systems of other technologies, social networks, and policies. In order for a technology to be disruptive, other parts of urban systems must change as well. Some of these changes are cultural in nature, and can only occur over the long term. Regardless, Malecki argues that the US planners are ill prepared to think about how technology will shape cities into the future.

### *3.3 Behavioral Theories: Economics*

The frameworks discussed above focus on central transportation problems of travel intensity and distance. All rely on a fundamental assumption that transportation is a "derived demand," and people gain utility from going somewhere – or communicating with someone – to engage in various activities (P. Mokhtarian & Salomon, 2001). This microeconomic approach to travel can inform planners not just when considering measures like trip counts or VMT, but also destination choices, and mode choice as well (Boarnet & Crane, 2001).

#### 3.3.1 Increased destination choice awareness

ICTs don't just make travel easier, they avail individuals of new activity choices, possibly resulting in new travel choices. Geosearch services, such as Yelp, Foursquare, and Google search, allow provide individuals with choice sets far larger than they would otherwise have relying on their own experience or traditional forms of search such as the Yellow Pages (Kelley, 2014). If an individual deems a choice outside of their traditional set to provide great utility, then they may choose to engage in travel they otherwise would not have. Whether expanded choice geographies result in more travel or less travel overall is not yet known. However, planners should seek answers to that question, as well as whether these types of search privilege some parts of the city over others.

#### 3.3.2 Create new markets for transportation services

Efficient markets are a core component of standard economic theory. Importantly, ICTs have allowed for the establishment of new or more efficient markets for services such as shared rides and access to vehicles, whether cars or bikes (Resnick, 2004). ICTs have allowed traditionally inefficient, highly regulated services such as taxis and car rental to be joined by transportation network companies like Uber, car sharing companies like Zipcar, and bike sharing programs in cities across the globe. Using ICTs to establish new markets across local geographies has been the secret to these new services success (Chan & Shaheen, 2012). Congestion and parking pricing, similarly, rely on efficient communication of prices to users to shift behaviors (Brownstone & Small, 2005; Chatman & Manville, 2013; Millard-Ball, Weinberger, & Hampshire, 2014).

### 3.4 *Behavioral Theories: Sociology*

Beyond economics, ICTs raise questions as to the nature of future urban societies. While potential problems are myriad, one stands out as particularly relevant to urban planners: social isolation. One of the hallmarks of sociological writing about contemporary urban environments is the sense of social isolation. Putnam's *Bowling Alone* (2000), is an indictment of contemporary suburbia for this reason, though other sociologists have presented contradictory findings (Gans, 1965). In terms of ICTs, their impact on social isolation remains highly uncertain. Online social networks and mobile communications have facilitated expanded social networks, both in scale and geographic scope. However, a focus on virtual or online communities may isolate individuals others in geographic proximity. One particular concern is the small but growing trend towards "virtualized" places, such as made possible by Google Glass (Kaufman, 2012a). How should planners treat spaces that are both real and virtual at the same time? Do planners face obligations to increase safety for walkers who may be, for example, seeing virtual advertisements as they walk down the street?

### *3.5 Behavioral Theories: Cognition and psychology*

A final set of theories relevant to the new technologies and mobility come from psychology. While the microeconomic approach to decisionmaking bases choices on maximized utility, psychological theories expand the factors that shape individual choices, accounting for cognitive and emotional factors.

#### 3.5.1 Replacement for cognitive map

The expansion of travelers' choice sets (see Section 3.3.1) is important not just because of where an individual may choose to go on a given trip. It is also important because relinquishing significant parts of everyday activity and travel choices to computers may have a significant impact on the human mind over the long term. Researchers have found that parts of the brain grow and shrink with increased navigational tasks, and more cognitively "passive" modes of travel result in a less accurate, expansive cognitive map (Maguire et al., 2000; Mondschein, Blumenberg, & Taylor, 2010). Thus, reliance on ICTs in travel decisionmaking may reduce independent mobility over the long term, even as it expands choices in the short term (Mondschein, 2012).

Building on the potential for a less developed cognitive map, humans may become more reliant on technologies for travel and their own ability to independently choice locations and navigate through the built environment atrophies (Middleton, 2011). For planners, this adds a critical dimension to the recent concern with urban resilience. If ICTs become wholly integrated into travel decisions, then resilience is not just a matter of maintaining transportation infrastructure in the face of disasters or long-term climate change, but also in maintaining the ICT networks being used for travel decisions.

### 3.5.2 Comfort and security of travel

One intriguing aspect of ICTs and their ability to make travel easier is that it reduces the sense of uncertainty and discomfort that accompanies many forms of travel in today's cities, whether taking mass transit or being stuck in traffic (Leung & Wei, 2000). New technologies provide individuals with more certainty about arrival times, how to use the system, and provide new opportunities distractions, such as distance working or music. All of these effects make travel all less stressful, emotionally burdensome activity. As vehicles become more autonomous and require even less engagement from individuals, people may be more likely to choose to travel, or even travel continuously as a part of their day. Just as ICTs can provide increased comfort, one very specific type of comfort they provide is a sense of security (Wei & Lo, 2006). Cellphones may instill in individuals the sense that help can be easily summoned, and their presence may also serve as a deterrent to potential criminals. Early research on the topic seems to show that cellphones facilitate activity, particularly walking activity, in parts of cities that have traditionally been marginal.

## 4 New Technologies within Transportation Planning and Practice

How can planners and other transportation professionals address new ICTs and other technologies with potential future impacts on transportation? Are existing planning strategies and frameworks sufficient? This section explores whether current practice has capacity, or relevance, to the new technologies.

### *4.1 Intelligent Transportation Systems*

Some of the technologies being discussed within the framework of Intelligent Transportation Systems (ITS), a primarily engineering-based, government-endorsed approach to incorporating new technologies into transportation systems (Barfield & Dingus, 2014; Sussman, 1996; Weiland & Purser, 2000). According to the United States Department of Transportation, ITS includes: vehicle-to-vehicle communications, vehicle-to-infrastructure communications, real-time data and information capture, synthesis, and dissemination, safety technologies, and electronic payment systems among other technologies (US Department of Transportation, 2014). These technologies include both ICTs and vehicular automation. Again according to USDOT, ITS benefits include objectives such as safety, reduced travel time, and more sustainable travel choices. ITS program objectives, thus, are largely in line with planning goals of increased transportation accessibility and sustainability. However, ITS does not prioritize one objective over another, rather just the integration of ICTs and other technologies into the mobility system.

### *4.2 Managing mobility*

While ITS is a multi-objective framework for managing technologies in transportation, other frameworks have specific objectives and remain agnostic on the tools for reaching those objectives. Two of the most important approaches to managing mobility in urban environments are Transportation Systems Management (TSM) and Travel Demand Management (TDM).

#### 4.2.1 Transportation Systems Management (TSM)

TSM is an approach to transportation planning which seeks to increase the capacity of existing infrastructure, whether roads, rail, or sidewalks (Gakenheimer & Meyer, 1977). Many TSM approaches are inherently technological, such as advanced signal systems such as Los Angeles' ATSAC. ITS-based approaches to autonomous vehicles, which posit that autonomous vehicles will be able to operate at greater speeds and more closely to one another than a human can manage are fundamentally TSM. Arguably, new markets for vehicles and parking are also TSM, as they allow for more efficient use of a given number of vehicles or land. In addition, many navigation and wayfinding apps provide travelers with the most time-efficient routes between locations, more efficiently distributing travelers across the network.

#### 4.2.2 Travel Demand Management (TDM) / Telecommuting

A subset of TSM, TDM specifically attempts to reduce travel overall, both to improve system efficiency and sustainability (Ferguson, 2000). One of the most noteworthy examples of TDM is telecommuting, an early example of ICTs and travel (Patricia L. Mokhtarian, 1998). Telecommuting is instructive because substantial research has been completed estimating its effects on travel. Initially, proponents of telecommuting TDM policies claimed the telecommuters would significantly reduce their daily VMT (Geels & Smit, 2000; Nilles, 1988). Subsequently, however, larger studies found that while telecommuting may have some small overall effect on VMT, that effect is not nearly as large as original estimates (Choo, Mokhtarian, & Salomon, 2005). Importantly, while overall VMT did not decrease significantly, shifts in time of travel and trip purpose were observed, with increased travel around the telework location (usually the home) for personal travel such as errands or meals.

ICTs also enhance other forms of TDM. For example, ridesharing has become far more efficient and widespread with services like Lyft, due to the ability of mobile applications and internet communications to create new markets for rides (Siddiqi & Buliung, 2013). Beyond telecommuting and ridesharing, many ICTs, particularly mobile apps, have been developed to ease the use of public transportation. Whether these apps have or can cause significant mode shift is not fully understood, though some evidence shows that marginal increases in transit use are due to transit-focused apps.

### *4.3 Open data and information dissemination*

One major area in which planners and transportation operators are engaging with ICTs is in the area of "open data" (Fioretti, 2011; Kaufman, 2012b). In this case, the long-held objective of providing travelers with better information for their travel decisions has been significantly enhanced as agencies, whether public transit or roadway operators, make their heretofore internal or undigitized datasets available to the public, especially software developers, online. Large and small transit agencies across the globe have begun putting information like schedules and real-time bus locations online, allowing developers to create apps that make using transit easier and potentially more reliable. Similarly, highway departments and other agencies are making traffic data more accessible, providing a similar experience for auto drivers and passengers (Peled, 2011).

### *4.4 Technologies for Transportation Planners*

Some technologies enhance the transportation planning process itself, either through the methods they allow or the data they generate. These technologies have the potential to vitiate transportation planning practice, those important caveats remain.

#### 4.4.1 Geographic Information Systems

Geographic Information Systems (GIS) has transformed planning practice potentially more than any other technology of the past several decade. GIS platforms and methods have moved out of the domain of geography professionals and are widely used in practice (Drummond & French, 2008). GIS facilitates visualization of complex patterns across cities, including transportation systems and travel patterns. Importantly, in the past several years, GIS has become more accessible to non-planners such as community members and advocates, allowing more widespread engagement with spatialized urban issues including mobility (Bugs, Granell, Fonts, Huerta, & Painho, 2010). Beyond GIS for planning practice, GIS underlies many ICTs, whether wayfinding apps, ride matching services, or online geosocial search. The ability to organize and visualize spatial information is essential for many of the mobility-enhancing technologies coming into use.

#### 4.4.2 Data for planning practice

Along with GIS as methodology, new data sources are a critical component of planners' engagement with ICTs. Many technologies generate copious amounts of data, both archived and in real time. These data allow more detailed understanding of travel behavior, traffic patterns, and system operations than has ever been possible in the past (Calabrese, Colonna, Lovisolo, Parata, & Ratti, 2011). One example, among many possible, of the usefulness of these data comes from New York City. When the City wanted to pilot a pedestrian plaza in busy, traffic-ridden Times Square, they relied on stored GPS tracks from taxis to show that traffic speeds did not significantly worsen, and in fact often improved, with the closure of several streets (Zhan, Hasan, Ukkusuri, & Kamga, 2013). The ability to demonstrate changes in traffic in near-real time with an already extant dataset made the analysis far more efficient and effective than traditional methods would have allowed.

Despite the appeal of new data sources, one important caution centers on data ownership. Many datastreams potentially useful for transportation planning are generated and owned by private companies (Goerge, 2014). These data streams can only be used if allowed by the company, which may itself be seeking to monetize ancillary uses of the data. Cities may and do enter into contracts with private companies to use the data, but these arrangements can be fraught. Thus, one intriguing development for planners is the advent of "small data," where local data is collected by the public, for public use.

### *4.5 Regulatory Approaches*

For some technologies, governments – Federal, state, and local – have begun to set the parameters, through regulation, for how some technologies may be deployed. The need for regulation is evident where issues of safety arise, so policies controlling the deployment of automated vehicles are being established rapidly across national and state governments (Smith, 2012). In addition, regulation of the myriad new vehicle for-hire and sharing schemas has proceeded quickly, due in part to safety and security issues, but also because these services present significant challenges to incumbent industries such as taxi service and transit providers, with significant effects on revenues and labor (Goldwyn, 2014). In terms of traveler use of mobile devices, safety regulation (if not enforcement) of driver behavior has proceeded relatively quickly, but regulation of walkers and cyclists has been more slow, resulting possibly in increasing injuries on urban streets (Stavrinos, Byington, & Schwebel, 2011; Tison, Chaudhary, & Cosgrove, 2011).

Outside of safety and work regulations, however, regulation of new transportation-related technologies is limited. Still, planners do play a significant role in ICTs which is rarely linked to some of the mobility implications discussed in this paper. Planners and other policymakers, through zoning and land use planning, have significant control over the location and function of ICTs own infrastructure. As the need for communication among vehicles, infrastructure, and users continues to grow, the infrastructure for that communication will need to be upgraded and expanded. Already, cell towers and the like are some of the most heated discussions in local land use boards (Hughes, 1997). As the ICT infrastructure becomes not just a convenience but a necessary component of the transportation system, these discussions are likely to become more heated and fraught.

## 5 Discussion

This review has explored the role of transportation planning in addressing mobility-enhancing technologies from three broad perspectives: historical, theoretical, and practical. Each perspective provides a distinctive ways of thinking about the issues are currently confronting, and are likely to need to address in the shorter and longer terms. Does a history of both tacit and explicit support for the introduction of new technologies in the past dictate that planners, and the public and private actors with whom must collaborate, must accept without argument automated vehicles or virtualized streets? Regardless of the ultimate answer, placing such dilemmas within a historic context can add provide insights such as potential impacts and their scale.

Similarly, I ask whether planners have the conceptual tools to think about the long term impacts of the myriad ICTs now coming to cities? In some cases, the answer appears yes. We can anticipate that reductions in travel costs, whether in terms of money, time, or cognitive burden, will likely lead to increases in travel. In other instances, planners need to deliberate a bit more, for exampling asking whether reliance on ICTs may lead to both cognitive degradation and a lack of resilience in our transportation system. For current planning practice, TSM and TDM frameworks can potentially provide useful practical approaches for supporting or seeking to mitigate many of the ICTs now being deployed. Regulatory action will likely ensure that roads will remain relatively safe, or hopefully become safer, despite new technologies and their potential for distraction. Still, planners have relatively few tools to analyze, much less manage, potential effects of social networks, online and mobile geo-search, and other activity-shifting technologies.

Based on these perspectives, what do should planners be doing now? Certainly, one fundamental need is more research on potential impacts of ICTs, individually and as a collective. The debate over telecommuting continued more than a decade before its effects were generally understood. Only limited research has so far been completed on the wide range of ICTs now in the field, though initial findings are beginning to make their way into the literature. For example, Fagnant and Kockelman (2014), find that combinations of autonomous vehicles and car sharing may lead to a 10% increase in travel distance, but with reductions in emissions partly due to the reduced numbers of vehicles produced. In transit research, Brakewood (2014) has found that real-time information has modest but positive impacts on transit ridership. More studies like this, using modelling or new data to analyze impacts is essential.

The review also highlights, by their absence in the literature, the need for research on ICTs impacts on transportation equity and sustainability. These aims are central for many planners, but frameworks for understanding differential effects of ICTs on populations defined by income, gender, race and ethnicity, age, neighborhood, or other factor are not well developed. Finally, this review highlights a problem, not unique ICTs but certainly relevant to them, with the way that planning practice and research is divided into silos such as transportation planning and land use planning. As transportation history shows, many of the impacts of mobility technologies are observed in land use and development patterns. Similarly, many of the activity-shifting ICTs such as online social networking and geo-search services may have neutral effects on overall travel, but are likely result in new distributions of activity, including spending patterns, that privilege some places over others.

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