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Space–Time Constructs for Linking Information and Communication Technologies with Issues in Sustainable Transportation

DONALD G. JANELLE* and ANDREW GILLESPIE**

**Department of Geography, Center for Spatially Integrated Social Science, University of California at Santa Barbara, CA, USA & **Department of Geography and Centre for Urban and Regional Development Studies, University of Newcastle, UK*

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ABSTRACT *This paper develops a conceptual framework for understanding the ways in which space-adjusting technologies relate to socio-economic patterns and processes, and it then explores some of the challenges that such a conceptualization poses for transportation research and planning. Special attention is given to a review of recent research on the integration of information and communication technologies within the transportation sector, concentrating on (1) the need to understand the underlying space–time dynamics of changes in mobility behaviour; (2) the role of information and communication technology adoptions in the structural transformation of cities and urban systems; and (3) the use of intelligent transport systems in facilitating efficient and sustainable mobility.*

Space–Time-adjusting Technologies and Socio-economic Processes

One of the remarkable facets of the integration between technology and social life is the capability of science, industry, and citizenry to see and implement new applications. They draw on an array of technologies, which, when combined in different configurations, can have potentially significant and, sometimes, unforeseen impacts on broad patterns of human settlement, production, and trade. Table 1 contains a listing of these technologies.

Four interrelated general concepts are fundamental to understanding the coupling between space–time-adjusting technologies and the processes that shape altered states of regional and community organization. These include the following:

- Time–space convergence.
- Time–space compression.
- Human extensibility.
- Trackability.

Correspondence Address: Donald G. Janelle, Center for Spatially Integrated Social Science, Department of Geography, University of California at Santa Barbara, Santa Barbara, CA 93106-4060, USA. Email: Janelle@geog.ucsb.edu

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Table 1. Space–time-adjusting technologies

Transportation
Communication
Wireless communication
Intelligent transportation
Location-based services
Information enhancement via:
Robotics
Expert systems
Smart cards
Digital storage media
Display technologies
Voice recognition
Image recognition
etc.

These processes permit the restructuring of human enterprise at all geographical scales and reduce, if not subvert, the usual constraints based on distance, spatial contiguity and temporal continuity. These processes have fundamental bearing for relationships among localities, regions and centres of global capital; for the spatial structures of communities, cities, metropolitan areas and regions; and for the information and communication technology (ICT)–transportation infrastructures that service their needs.

Time–Space Convergence

Time–space convergence describes the rate at which the travel time between places declines in response to transport and communication innovation and investment (Janelle, 1968). Thus, historical data reveal that London and Edinburgh have converged upon one another at an annual average rate of 29 minutes/year from 1776 to the mid-1960s. This concept of places moving closer together or further apart (time–space divergence) imbues space with a sense of dynamics derived from the embedding of time as the basic functional metric of distance. However, the notion of a average annual rate of convergence hides some of the most significant features of the convergence process. Among these are the following:

- There is unevenness to the convergence process over space — resulting from the variable investment patterns that privilege the expanded accessibility of some places and regions over others. There is also unevenness in convergence patterns over time, reflecting temporal discontinuities in funds for investment, availability of technologies, lags in decision-making implementation and the politics of policy-making.
- Within any regional economic system, there is variability in the capabilities of people, groups, and institutions to take advantage of transport and communication systems. Hence, selective patterns of convergence and divergence underscore social and regional cleavages based on class and other notions of socio-economic status.
- In general, convergence has operated at regional and global scales, with places getting closer together, whereas time–space divergence has operated at urban

scales, with inner-city and suburban regions suffering from the impacts of congestion.

- There is an inevitable (natural) bias to any transport and communication investment that favours the most distant places served by the new development. For example, the uniform doubling of travel speeds along a route will result in convergence rates that favour places in direct proportion to their average distance to all places served by the new development. While this may be an advantage for the periphery over the centre of a national or regional economy, in practice the ability of places to capitalize on these changes is a function of their positions in the economic hierarchy. Time–space convergence rates mirror the hierarchical structure of settlement systems.
- Possibly, because of difficulties in portraying these complex patterns spatially as maps of change over time and over space, the issues of equity and accessibility at individual, regional and global levels remain poorly understood. The cartographer Tobler (2001) notes that while the world is shrinking, it is also shrivelling and fragmenting, making cartographic renderings very complex. Nonetheless, noteworthy attempts are seen in the work of Bretagnolle *et al.* (1998) in characterizing transport-induced convergence within Europe and in the time-based distance map of Spiekermann and Wegener (1994) to portray the impact of the TVG high-speed network on the space–time structure of Europe. As if the mathematics of such representations is not complex enough, Miller (2002) calls for methods of analysis that go beyond cartographic generalization and the technology of geographic information systems (GIS) to "encompass dynamic, mobile and active objects that operate within a dynamic geography at multiple spatial and temporal scales". AQ2

Time–Space Compression

Time–space compression, as advance by Harvey (2001), is quite distinct from time–space convergence. Harvey allies the compression concept with Karl Marx and the annihilation of space by time, but focuses on the accelerating throughput of events in daily individual life, thereby giving a strong experiential basis to the impact of modern technologies. He sees this intensified pace of existence as dehumanizing social processes by detaching people from place and history. The concept underscores the ability of technology to accelerate the flow of capital, land-market transactions, production, and consumption — the accumulative processes of capitalism.

Given the negative externalities of energy depletion, environmental degradation, and both social and psychological stress associated with capital accumulation, O'Kelly (2002) asks whether or not selected 'disimprovements' in accessibility are desirable? For some sectors of the population or for selected regions, maybe it is time to reverse the intensification of human daily activity to more manageable levels acceptable to social wellbeing.

Human Extensibility

The concept of human extensibility (Janelle, 1973) describes how individuals and institutions use technology to project their presence and ideas beyond their immediate locales. Achieved slowly via word-of-mouth transfer of ideas and traditional postal service and other transport linkages, today, via the Internet,

anyone with a computer and Internet service will have nearly instant access to a billion or more users. The Internet transforms radically the ability to extend one's presence at geographical scales far beyond local regions and to do so simultaneously with any number of other individuals and institutions.

Human extensibility and the implosion of the world on the individual (time–space compression) represent simultaneously opportunity and threat — the opportunity to communicate and engage in dialogue and commerce, and the threat of besiegement and incapacity to absorb or cope with relentless volumes of information calling for attention. Clearly, the temporal aspects of this problem require abilities to engage and disengage in one's connectivity to the world — to network selectively or to broadcast universally, as required. Couclelis and Getis (2000) observe that since many human activities are increasingly less connected to specific places, there is need for new theoretical constructs about the role of place in society.

Another important dimension of human extensibility is the ability of individuals to maintain a multitude of personal networks (e.g. familial, professional, recreational), almost at will, regardless of their specific location at any point in time. In the sciences, 'invisible colleges' (Crane, 1972) have been enhanced immeasurably by e-mail and Internet access and via Web search engines (e.g. www.Google.com) that permit the easy discovery of those with compatible and complementary interests and skills. Networks of researchers use these tools for outreach and for information dissemination to organize their activities of intercontinental exchange and knowledge development. Examples in transportation research include the Sustainable Transport in Europe with Links and Liaisons with America (STELLA; www.stellaproject.org) and Sustainable Transportation Analysis and Research (STAR) networks. Such networks use ICT technologies to foster human extensibility in a broad range of fields that enrich personal and intellectual life and enhance the scope of scientific research activities.

Trackability and Location-based Services (LBS)

Individual people increasingly enjoy mobility, connectedness with others, and flexibility of activity in time and space, especially if they have access to automobiles, cell phones, personal digital assistants and computers. While these tools are great facilitators of personal time–space convergence and extensibility, they also provide a means for tracking in detail an individual's behaviour, even the whereabouts of entire population cohorts.

Willingly or not, the travel and communication activities of individuals and institutions are being increasingly monitored. Global positioning system (GPS) and cellular technologies "enable mobile electronic devices that are capable of measuring their position on the Earth's surface, and of modifying the information they collect and present based on that knowledge" (Goodchild, 2002, p. 1). An emergent economy of LBS is increasingly commercializing these tracking capabilities to target information, and services to clients based on where they are located at any given time (Kim, 2002). Hjelm (2002) reviews the many possibilities and issues associated with the delivery of information-based services through LBS technologies. The expected convergence of different portable technologies (e.g. cell phones, personal digital assistants, laptops, palm computers, tablets) into a single personal information utility no doubt will intensify trends in the commercialization of services based on the tracking of mobile objects. Along with external surveillance cameras, digital records of credit card transactions, and logs of

computer e-mail activity, the trackability of people is a substantial new component of individual existence that was not present a generation ago. Questions arise over personal privacy and the social implications of such pervasive records and their possible uses (Curry, 1997; Graham and Wood, 2003). In addition, these technologies permit new kinds of social and economic networks, and are likely to incur new forms of social and economic behaviour, and altered lifestyles (Townsend, 2001; Gillespie, 2002). It is still too early to know how all of this will affect spatial patterns of land use and human activity, and impact on transportation demands. But clearly, this requires careful consideration by researchers interested in the understanding and planning of transportation and communications systems. As demonstrated by Martinotti and Boffi (2002), these technologies give access to new sources of data about daily mobility and about the territorial context of urban life. They are capable of providing information that can be critical for both scientific understanding and policy formulation.

Implications of Space–Time-adjusting Technologies for Sustainable Transportation Research and Planning

In combination, convergence, compression, extensibility and trackability pose enormous potentials and challenges in the transportation sector. One can envision a world of flexible spatial alliances, new kinds of spatial organization for production and distribution, more time- and space-responsive forms of decision-making, possibly new systems of supply-chain management, new labour contract arrangements that alter commuting behaviour, and a renewed focus on just-in-time behaviour based on synchronization of resources and activities. As Couclelis (2000) points out, however, these kinds of responses and innovations pose serious dilemmas for sustainable development — the ability to maintain such social and economic arrangements for foreseeable generations.

For the transportation and regional science research communities, these trends provide new tools for gathering data, but their understanding will likely require modelling frameworks based on new conceptualizations of space–time structures in relationship to social and urban–regional systems. It seems likely that there will be greater focus on space–time activity patterns and modelling. The implications of LBS for transport systems and sustainable transport will influence freight logistics, and raise issues about the social and environmental context of intelligent transport.

In a world of such flexibility, one wonders if the dominant paradigms from engineering and neo-classical economics (optimization, maximization, efficiency, cost effectiveness, prediction) will or should prevail. Challenges to the dominant paradigms may arise as people begin to question the desirability of mobility, or as they fashion structural changes in societies and economies based on objective functions derived from non-traditional value systems (e.g. environmentalism), etc.

Table 2 presents three general areas of human social dynamics related to the integration of information and communications technologies in transportation. These include individual mobility, emergent urban form and the transportation–ICT system itself — as a primary conduit for human enterprise. Each area is paired with each of the four space–time concepts: convergence, compression, extensibility and trackability. The intersecting cells of the resulting matrix identify areas of basic research and policy consideration central to any effort to analyse, model or manage the dynamics of individual behaviour, urban development or

Table 2. Integrating time–space concepts with capabilities for analysing, modelling and managing the dynamics of individual, urban and transportation–information and communication technology (ICT) systems

Concepts: Dynamics:	Time–space convergence	Time–space compression	Human extensibility	Trackability
Individual space–time dynamics	Analysing and modelling transaction speeds for transportation and communication	Modelling the intensification of transactions per unit time and per unit space	Modelling geographical reach and potentials for network contacts	Real-time dynamic mapping of individual activity paths
Urban-form dynamics	Modifying the potential boundaries of urban spatial interaction fields and altering patterns of land use specialization	Integrating ICT and transportation for congestion relief and the timing of spaces and regions (e.g. the 24-hour city) for greater sensitivity to time pressures and to the spatial clustering of events	Expanding potential access to the full range of opportunities within the urban sphere, and expanding the possible range of commercial and social interactions from fixed locations (home and workplace) and from mobile platforms	Monitoring, displaying, analysing and forecasting activity patterns within urban regions
Transportation –ICT system dynamics and responsiveness	Facilitating more efficient and timely transportation and communication	Establishing greater control over the number, timing and integration of events in social and economic life	Improving the opportunity base, especially for disadvantaged groups	Real-time detection and management of flows through transport and communication networks; scheduling transport services to meet individual and regional needs

demand-responsive mobility systems. The following sections address these three levels with regard to the identification of research issues and questions about sustainable mobility and settlement systems.

Individual Space–Time Dynamics

Researchers and planners have recognized needs for explicit consideration of temporal factors in the development of future transportation options for cities and regions. These needs are recognized explicitly in the trends toward disaggregate analysis and modelling to improve theoretical understanding and policy evaluation. Much of this works builds on the conceptual breakthroughs by Hägerstrand (1970), especially in the modelling of individual activity behaviour (Doherty, 2003; Dijst, 2004) and in dynamic geovisualization methodologies (Kwan and Lee, 2004).

In North America and Europe, geographers have played prominent roles in extending the underlying theory of time geography (Miller and Wu, 2000; Kwan

and Dijst, 2002; Shaw and Xin, 2003) by re-visiting the 'space–time prisms' concept within the context of the 'human extensibility'. They are also considering the impact of ICTs on accessibility to economic and lifestyle opportunities. Three-dimensional GIS techniques are permitting the visualization of the complex ways in which ICTs are altering the space–time constraints of daily life. These techniques add insight about how people respond to the opportunities provided by time–space convergence processes and how they cope with the pressures of time–space compression at individual, family and workplace levels. In addition, tracking technologies are enabling access to data that will enhance significantly the information resources for transportation research and planning. Examples of important demonstration projects include the experimental GPS tracking of vehicles in Lexington, Kentucky (Battelle Memorial Institute, 1997), and work in Canada (Doherty *et al.*, 2002). In the Canadian work, Lee-Gosselin (2002) has reviewed the emerging scope for GIS and GPS techniques for a range of innovative research methodologies to study transport behaviour, including travel surveys, micro-behavioural modelling and activity pattern visualization in space–time. These initiatives show promise for extending the empirical analytic value of time–space activity diaries, exemplified in the time geography of a Canadian city (Halifax) project by Janelle *et al.* (1998) and in a major new initiative by Harvey (2004) to collect GPS-based activity surveys for 5000 respondents in the Halifax area.

Another area that requires significant survey research concerns questions about the integration of Internet and cell phone technologies in the management of personal travel. Some recent small-scale studies in Europe and in North America are moving in this direction (Casas and Thill, 2004; Kwan *et al.*, 2004; Nobis and Lenz, 2004). Kwan (2002) has exploited visualization techniques to investigate how virtual and physical extensibility are integrated into the emerging activity patterns that influence daily life and commerce at local to global scales. Lee-Gosselin (2002), however, cautions researchers to address uncertainties in the human responses to new ICT technologies and he questions the ability of policy-makers and planners to anticipate these new behaviours.

In general, while survey research remains a primary need, significant progress has occurred in the basic technical breakthroughs for treating the dynamics of individual behaviour, paralleling Miller's (2002) call for a methodology that treats AQ3 "dynamic, mobile and active objects … within a dynamic geography at multiple spatial and temporal scales". He asserts "the static and place-based organization of data and information in most geographic information systems (GIS) is ineffectual as an analytical platform to answer key questions at the forefront of transportation and urban theory and policy". He advocates using the technologies of LBS to conduct large-scale, cross-national collections of space–time activity data that feature varied contexts for exploring basic research and policy issues (regions with different geographic, social, economic, demographic, cultural and technological attributes) and broad application of the time-geographic perspective. An area of application is in the development of space–time diary data for comparative research at intra-urban scales.

Urban Form Dynamics

Most researchers agree that the impact of the digital revolution on individual behaviour (e.g. life styles, work practices, and associated patterns of travel and commerce) is in a reciprocally causal relationship with the changing spatial forms

and functions of cities. However, the precise nature of such relationships remains poorly understood. Gillespie (2002), Giuliano and Gillespie (2002) and Gertz (2002) have explored links between urban form and ICT adoption practices, raising questions about their implications for sustainable development. Among the important questions identified for investigation are the following:

- To what extent does e-commerce (e.g. teleshopping) affect patterns and processes of people and freight movement logistics within urban regions? Van Geenhuizen (2002) offers a conceptual framework for evaluating this and related questions, while Lake and Cherrett (2002) provide an overview of recent research.
- How does telecommuting (telework) affect the spatial link between residential choice and work behaviour? How are trip patterns and choice of transportation mode influenced by uses of ICT? These questions have been explored most intently by Mokhtarian (1998) and colleagues, drawing together empirical findings about formal telecommuting efforts in California and assessments of their policy value for mitigating transportation problems in urban areas. Lake (2003) provides one of the more inclusive reviews of known findings in this area, though he acknowledges that the findings are weakened by the paucity of large-scale and comprehensive investigations.
- What are the implications of wireless technologies for social and commercial behaviour and how will they affect the timing and spacing of land uses and activity systems in urban environments? On this question, Townsend (2001, 2004) presents a provocative perspective on emergent behavioural practices of urban residents and raises questions that require consideration by planners and policy-makers.
- What is the link between ICT use at individual, household and firm levels and the changing land-use patterns and trip distances within metropolitan areas? Empirical research has not yet come to grips with this question, but micro-simulation modelling initiatives (Nagel *et al.*, 2004; Salvini, 2004) show significant promise.

Although researchers have probed these questions, answers remain tentative. The approaches include detailed but as yet piecemeal and small surveys of individuals, households and firms on the uses of ICT (Casas and Thill, 2004; Kwan *et al.*, 2004; Nobis and Lenz, 2004) with speculation about their importance to broader issues of urban land use structure and patterns of metropolitan interaction.

One of the more promising approaches for exploring interactive relationships among 'virtual mobility', transport, and urban environment and land-use patterns is through agent-based modelling (Nagel *et al.*, 2004; Salvini, 2004). The utility of these models relies heavily on solid empirical grounding and on the ability to embed behavioural rules that are both consistent with observed behaviour and with plausible policy-making environments. An exciting development in this area is the convergence of space–time modelling of individual behaviour and of geo-visualization tools with the ability to investigate patterns and processes at a variety of scales related to metropolitan processes — at neighbourhood, district, city and larger levels of analysis. Nonetheless, the general gap between research knowledge and the information needs for formulating policy recommendations is a stark admission that the urban form implications of ICT adoption remain highly uncertain.

Transportation–Intelligent Transport Systems System Dynamics and Responsiveness

ITS span a broad range of applications to enhance the automation and efficiency of transportation infrastructure and logistics (European Commission, Energy and Transport DG, 2003). At the interface with human behaviour, these technologies appear most significant in reducing uncertainty in decision-making, increasing reliability of services, providing seamless implementation of a user-pay principles, and providing greater safety and security in the movement of people and freight. Miles and Hoose (2003) cite institutional obstacles, such as funding and technical standards, that warrant broad strategic coordination to ensure interoperable deployment of ITS services at regional and national levels.

While there are many facets of ITS that warrant consideration, the focus here is on implementing equitable demand-responsive transportation (DRT) services that are sensitive to the dynamics of individual behaviour and to the changing forms of human settlement systems. Through provision of information to the users and agents of transport, when and where it is needed, DRT and other ITS technologies facilitate time–space convergence and extend the benefits of space–time extensibility to those who can take advantage of such systems. Grieco (1995), noting the intense time pressures on low-income families as a consequence of poor transit coordination for meeting household needs, advocates targeting such services to those currently under-serviced with accessibility to social and economic opportunities. Social exclusion and neglect of low-income communities in the provision of accessibility are major issues that can be addressed through ITS-supported DRT services. Carter and Grieco (2000) and Grieco (2002) advocate planning paradigms that improve social equity by applying DRT strategies to service traditionally mobility-deprived communities. Mageean and Nelson (2003) illustrate and evaluate such approaches to public transportation in rural regions of the UK.

While ITS offer potentials for safer, more secure and more efficient transport, social-science perspectives are essential to the formulation of suitable policy environments for implementing DRT and other applications. For instance, the different models used for ITS deployment in different regional and national settings provide context for potentially valuable comparative studies regarding both the environmental and social sustainability of ITS-based development options. The 'social construction' of ITS in Europe, North America and other regions, and the analysis of the various actor networks involved in its development, are topics worthy of investigation that could contribute understanding of how new technologies are socially constructed and embedded in the distribution of authority, power and opportunity.

Conclusions and Suggestions for Further Research

This review concludes that new ICT technologies can be key drivers in the enhancement of equitable distributions of transport infrastructure. However, for transport and ICT systems to be contributors to sustainable economic and social development, researchers and policy-makers must address a number of significant issues. For example, they 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 populations from destructive uses and impacts of space-adjusting technologies.

A fundamental research need is to determine the extent to which mobility (the consumption of distance) is intrinsic to human society. For example, O'Kelly (2002) challenges the societal and technical focus on time–space convergence, as opposed to time–space divergence, and raises the possibility (if not the desirability) of reversing the processes of time–space compression. These represent fundamental questions about the nature of space adjustment to the ever-changing technologies that link individuals, communities, cities, regions and the global system. They also raise concerns about policy assumptions that ICT and other technologies can yield more sustainable transport systems. For instance, Banister *et al.* (2004) question the standard expectations about ICT applications in contributing to sustainable patterns of trip generation, distances travelled and other key indicators that influence levels of congestion, fuel consumption and pollution. They model scenarios on the basis of plausible alternative assumptions related to the values of a free-forming electronic society, a business efficiency-oriented paradigm and a society driven by 'smart' social policies. In the European context, their observations suggest that even strong policy actions may be insufficient to affect long-term directional shifts consistent with goals of sustainability. However, lack of significant empirical work in a sufficiently broad set of case studies remains an obstacle to reducing conceptual and factual uncertainties on the impact of ICT on transport demand.

Nearly all domains of transportation analysis and development will benefit from a better understanding of behaviour at the individual level and a better understanding of how shifts in individual behaviour translate into changes in the forms and functions of cities and metropolitan regions. These include the temporal cycles that operate at daily, weekly, annual and lifetime scales; the timing of work and the provision of social services; the activity–time budgets of individual citizens and firms; options to travel at different speeds; the need for synchronization of diverse economic and social practices; and logistics timing in the production and management of transportation systems. Issues on the efficiency, effectiveness and equity of transportation cannot be resolved without careful consideration of the temporal domains of individual lives, local and regional societies, and the global community. It is in this broad context that the integration of new tools of communication and information exchange offers unparalleled opportunities and challenges for resolving critical transport needs. Reggiani (2002) summarizes these observations as a 'change of paradigms' focused on the dynamics of accessibility and their impacts on urban form and changing patterns of supply and demand in transport, intermodality and the value of time. High on the research agenda is the need to cast the models and techniques associated with these new paradigms with theoretical frameworks and analyses that are transparent and relevant to the needs of policy-makers.

AQ4 **References**

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