TravelBehavior.com: Activity Approaches to Modeling the Effects of Information Technology on Personal Travel

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1. OBJECTIVES

This paper puts forth some ideas for extending travel behavior modeling to account for interactions between travel and telecommunications. Information technology (IT)[1] is burgeoning, providing unlimited business opportunities for entrepreneurs to develop and sell IT products and services. While most of these products and services are not specifically designed to affect travel behavior, they do, often in subtle and unexpected ways. The connectivity of the Internet and the proliferation of capable and affordable home computers and communication devices have encouraged flexible work arrangements and made e-commerce the fastest growing sector of most western economies. For many people, the home has become a viable site for the conduct of certain activities that formerly could only be conducted at non-home locations. In addition, cellular telephones and other portable computer and communications devices have redefined our ability to conduct business and dynamically schedule activities while traveling or at locations away from home or workplace. The wave of technological advances that brought us the Internet, mobile phone, and personal digital assistants (PDA's) is not slowing down. The future will bring a next-generation Internet with higher speed, multimedia capability and intelligent agent technology. It will be accessible by both PC's and "Internet appliances" such as television set-top boxes, videogame consoles and smart handheld devices.

Accessibility can no longer be measured only in terms of travel time, distance or generalized travel cost. Information technology gives individuals **virtual accessibility** to a rapidly growing range of activities. Each person who shops at home on the Internet, or uses a handheld Internet device to gather information about the transportation system before embarking on a trip, might only change his or her overall pattern of travel behavior just a little. But there are millions of people worldwide who will be doing similar things on any one day. The small effects scale up to be significant. Travel behavior researchers need to develop models of activity and travel behavior that are capable of capturing the present and future impacts of telecommunications on activity and travel behavior. This paper is meant to explore how we might do that.

2. BACKGROUND AND SCOPE

At the last IATBR conference in Austin, Mokhtarian and Salomon (1997) presented an overview of research issues in the study of telecommunications and travel patterns. They considered studies on both the macro and micro scale, but limited telecommunications to point-to-point interactive communications networks. This paper

[1]IT is also variously referred to as information and communications technology (or information and computer technology) (ICT) or new information technology (NIT). The period of new IT is synonymous with the "information age," the "information revolution," the "information society, the "information superhighway" the "digital economy," or variations on this themes.

builds upon that review and the subsequent report from the 1997 IATBR workshop on travel-telecommunications interactions (Hensher and J. Golob, 1997).

The present discussion is limited to behavioral analyses and modeling at the household and individual level, and the focus is on activity behavior. Activity behavior treats travel as being derived from the demand for activity participation. Some activities involve travel, while others do not, and travel is viewed in the broader picture of activity scheduling in time and space. Activity-based approaches to travel demand modeling are not new, but their use as a means of capturing telecommunications and travel interactions is in its infancy. Research opportunities abound in the present and should greatly increase in the future.

This is not meant to be a comprehensive review of activity-based approaches, which were first proposed in detail in the early 1980's. Early efforts are reviewed by Axhausen and Gärling (1992), Damm (1983), Kitamura (1988), and Kurani and Lee-Gosselin (1997). Several excellent overviews of more recent activity-based approaches have been published during the decade of the 1990's, including papers presented at previous IATBR conferences. The reader is referred to the following reviews: Bhat and Koppelman (1999), Bowman and Ben-Akiva (1997a), Jones, Koppelman and Orfeuil (1993), Kitamura (1997), Pas (1997a) (1997b), and Pas and Harvey (1997).

This paper concentrates on IT influences on personal travel behavior. It is not meant to be a general discussion of the broader impacts of new information and communication technology (IT).[2] However, this presentation does review forecasts of IT, while fully recognizing the uncertainties in these forecasts. We all know that essentially nobody was able to forecast the growth of the Internet in general and consumer e-commerce (online shopping) in particular. IT professionals constantly remind each other of the famous words of Ken Olsen, chairman and founder of Digital equipment Corporation, in 1977: "there is no reason anyone would want a computer in their home." Perhaps now, with the current depth of technology penetration, such forecasts will prove to be more reliable, but quite possibly history will repeat itself.

The remainder of this paper is organized into five major sections. The next section discusses technological advances that are most likely to affect activity and travel behavior. This is meant to set the stage for the following section that discusses present and future impacts of IT on activity and travel behavior. Then come a section on research directions, followed by one on data needs. It all ends with a conclusions section.

[2] There are many excellent overviews of the potential impacts of IT on spatial environments. See, for example: Bertuglia and Occelli (1995), Capello and Nijkamp (1996), Castells (1996), Droege (1997), Graham and Marvin (1996), and Mitchell (1995).

3. RELEVANT INFORMATION TECHNOLOGY

3.1. Home Computing

In 1964, Gordon Moore, a founder of Intel Corporation, predicted that the processing power of microchips would continue to double every eighteen months. So far, "Moore's Law" has continued to hold true. This increase in computing power and corresponding decrease in cost has made personal computing resources available to almost all businesses, schools, and most households. Technological advances in microchips have also made portable computers more capable, affordable, and compact. Many persons use portable computers in a multi-function way both for work and household activities. Many also now use very small portable computers (e.g., personal digital personal assistants, or PDA's), and the capabilities of these devices will increase greatly over the next few years.

All that was needed to make personal computing attractive in business settings was appropriate applications software, efficient and intuitive user interfaces, and local area networks. However, these advances alone were not sufficient to make personal computing attractive for non-work applications in households. What was needed was connectivity to the outside world – virtual accessibility. This is provided by the Internet, which is discussed in the next section. By 1999, computers were in about 44 percent of U.S. households.

The vast market for the hardware and software technology by which home computers can be connected to the Internet is ensuring that technological developments keep pace with demand. In the late 1990s, dial-up modem speeds increased and costs decreased until the limitations of twisted-wire telephone connections were reached. This has since been followed by television cable modems and DSL (digital subscriber lines). The number of broadband Internet connections to homes in the U.S. is forecast to increase by 250% from 1999 to 2000 (source: IDC, 1999). In 1999 there were approximately 1,500,000 cable modems in operation, and the number is forecast to reach 45 million by 2007 (source: Pioneer Consulting, 1999). The future is also likely to include set-top boxes, which enable television sets to become interfaces to the Internet. These devices, which are essentially specialized computers loaded with TCP/IP and web HTP clients (Web browsers), might be attractive to new segments of the population who have not become familiar with traditional computers through work or educational experiences. Videogame consoles are now also going online and will likely provide future set-top Internet access that goes beyond online multi-player gaming. Videogame manufacturers are all linking up with Internet providers to develop online devices, some of which come with built-in modems (Industry Standard, 1999). IT industry consultants (e.g., Gens, 2000) predict a transition from home computers to "information appliances".

The next technology in the sequence appears to be satellite-based Internet distribution services (Minei and Cohen, 1999, Pioneer Consulting, 1999). Throughout the 1990's, direct satellite links from homes were marketed almost exclusively for television broadcasts. The forecast is that this will rapidly evolve to marketing of combined television and Internet services. The ultimate advantages of satellite Internet connections are faster access time, lower cost, distance insensitivity, and bypass of terrestrial network bottlenecks and problems. This will also potentially expand high-speed connectivity to residential areas poorly served by other technologies.

3.2. The Internet

3.2.1. A Short History of Computer Networking and the Internet

The foundations for the Internet were laid in the development of packet-switching network technology in the 1960's. Until then, most information was transmitted via telephone networks that used circuit switching, which is appropriate for constant rates of voice transmission. However, information transmitted between computers comes in bursts, and researchers working independently at MIT, the Rand Institute, and the National Physics Laboratory in England used queuing theory to develop packet switching, an efficient and robust alternative to circuit-switching for computer networks (Kurose and Ross, 2000). The first packet-switched network, ARPANET, is considered the direct ancestor of the Internet.

Beginning in 1969, ARPANET linked four nodes, at (in order of hook-up): (1) UCLA, (2) Stanford Research Institute, (3) University of California, Santa Barbara, and (4) University of Utah (Leiner, *et al.,* 1998, Zakon, 2000). This was funded by the Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense. By 1971 the network had grown to 15 nodes with 23 hosts (a host being a computer system with a separate registered address). In 1972 the first computer-to-computer chat, a predecessor to email, took place on ARPNET. In 1973 the first international connections (University College, London and NORSAR, in Norway) were made to the ARPNET, whose users were then estimated at 2,000. 1974 saw the advent of TCP, a Transmission Control Program (later evolving to TCP/IP), and the first packet data service, Telnet, was released as a commercial version of ARPANET. 1975 saw the first satellite links and the first email mailing lists. The Ethernet protocol, published in 1976, allowed multiple access in wire-based local area networks (LAN's). Ethernet, based upon the 1970 Aloha protocol for shared radio transmissions in the Hawaiian Islands, represented an important step in the development of internetworking (Kurose and Ross, 2000).

Other networks soon came on line and were eventually linked together: USENET (1979), CSNET (1981), and BITNET ("Because It's There Network" in 1981). In 1983 the name server was invented, and in 1984 the domain name system (DNS) was introduced. By 1984 the number of networked hosts reached 1,000. In 1986, the United States National Science Foundation (NSF) greatly enhanced connectivity by establishing the NSFNET backbone among five university super-computer centers (Princeton, Pittsburgh, San Diego, Illinois and Cornell). More networks emerged, and by 1987 there were over 10,000 hosts; by 1989 there were 100,000. ARPANET was finally phased out in 1990.

Paralleling this burgeoning of computer networks, in 1980 the French government launched Télétel, a Videotex telephone-based packet-switched network originally designed to provide an online telephone directory. In 1984 the French government began distributing free Minitel terminals with low-speed modems to any French household that applied for one. By 1995, Minitel offered more than 20,00 different free and user-fee services, ranging from directories to banking and reservation systems, and it was used by over 20% of the French population (Kurose and Ross, 2000). A precursor to Internet-based consumer e-commerce (Section 3.2.1), it spawned similar Videotex systems in other countries (e.g., Prestel in the U.K.) and is still in widespread use in France.

In 1991, The World Wide Web (WWW) was released by CERN, the European Laboratory for Particle Physics. The WWW pioneered the use of HTML (hypertext markup language), HTTP (hypertext transfer protocol), Web servers, and Web browsers. The number of interconnected network providers continued to grow throughout the early 1990's, and in 1991 NSFNET reverted back to a research network. By 1992, the number of network hosts reached 1 million. GUI (graphical user interface) Web browsers came into being in 1993 and 1994 with the release of Mosaic (which became the foundation for Netscape). In 1995 dial-up Internet connections began to be provided in the U.S. by for-profit companies (e.g., Compuserve, America Online, Prodigy). There were estimated to be approximately 5,800,000 Internet hosts in January 1995. This number grew to about 56 million by July 1999, as graphed in Figure 1 (Zakon, 2000).

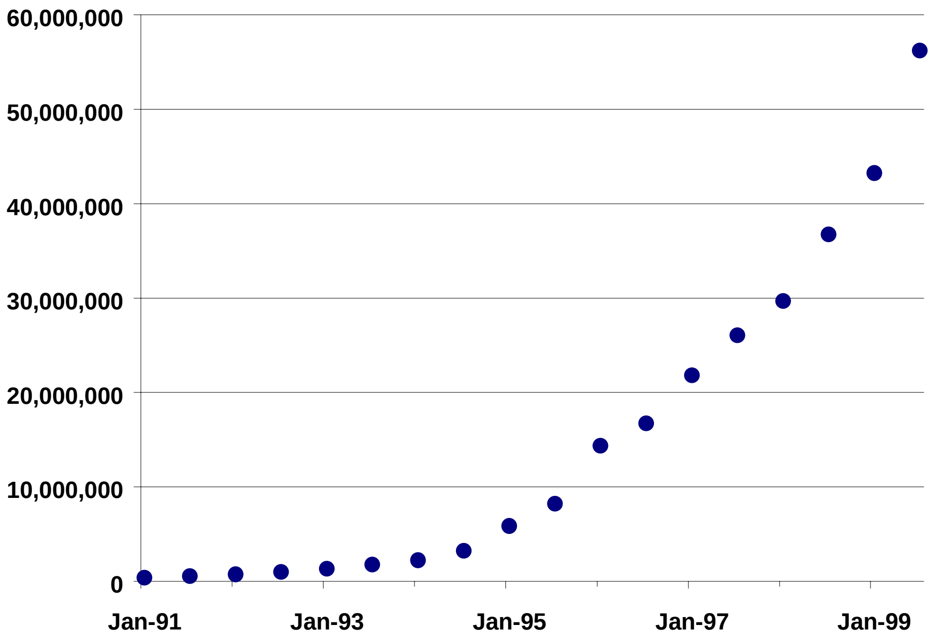

Figure 1. Growth in Internet Hosts, 1995 to 1999

3.2.2. Current State of the Internet and Future Prospects

In 1999, the Internet grew by 60,000 Web pages a day, and at the end of the year there were more than 5 million registered domain names. The number of Web pages is forecast to grow to 7.7 billion by 2002 (IDC, 1999). Estimates vary, depending on what is being measured and how it is being measured, but it is generally agreed that, at the present time, Internet traffic currently doubles every eight months or so. During the one-year period February 2, 1999 to February 4, 2000, the number of worldwide Internet hosts increased 46%, from 47.57 million to 69.62 million (Telcordia, 2000). The breakdown of the 71.56 million current Internet hosts, as of February 10, 2000, by major top level domain is shown in Table 1 (Telcordia, 2000). International comparisons are difficult because of the ambiguity of the generic domains (.com and .net).

Table 1: Total Internet Hosts for the Major Top-level Domains as of February 10, 2000 (in thousands)

ar	201	Argentina	it	604	Italy
at	257	Austria	jp	2,673	Japan
au	1,012	Australia	kr	281	South Korea
be	333	Belgium	mil	1,920	generic: US military
br	359	Brazil	mx	255	Mexico
ca	1,728	Canada	my	59	Malaysia
ch	307	Switzerland	net	15,435	generic: network provider
cl	43	Chile	nl	809	Netherlands
cn	50	China	no	397	Norway
co	37	Columbia	nz	252	New Zealand
com	27,217	generic: US commercial	org	987	generic: US organization
cz	113	Czech Republic	pl	193	Poland
de	1,596	Germany	pt	075	Portugal
dk	323	Denmark	ro	24	Romania
edu	6,578	generic: US educational	ru	194	Russian Federation
ee	27	Estonia	se	596	Sweden
es	432	Spain	sg	128	Singapore
fi	621	Finland	si	21	Slovenia
fr	805	France	sk	25	Slovakia
gov	818	generic: US government	su	13	Soviet Union
gr	77	Greece	th	35	Thailand
hk	100	Hong Kong	tr	82	Turkey
hu	131	Hungary	tw	560	Taiwan
id	21	Indonesia	ua	39	Ukraine
ie	55	Ireland	uk	1,954	United Kingdom
il	147	Israel	us	1,627	United States
in	26	India	uy	16	Uruguay
is	24	Iceland	za	165	South Africa

The number of worldwide Internet users (adults over sixteen engaged in weekly Internet access from home or business) was estimated at about 182 million at the end of 1998 and stands at well over 200 million today (source: IDC, 1999). Forecasts of growth vary, but one source (Computer Industry Almanac, 2000), predicts 766 million worldwide by 2005, more than a four-fold increase in five years. Another source (IDC, 1999) predicts a billion-user Internet in 2005. In 1998, almost half of all adult Internet users resided in North America. But, as shown in Figure 2 (based on data from Computer Industry Almanac, 2000) this is expected to change as other parts of the world become connected. By 2005, both Western Europe and the Asia-Pacific region are each expected to have almost as many Internet users as North America. The total numbers of Internet users in the rest of the world will be considerably less than in these first three regions, but the proportional increases in the number of users in the Middle east and Africa, South and Central America, and Eastern Europe could be phenomenal. At the present time, it is estimated that the average Internet user in the U.S. spends 12.1 hours per week online (source: Intelliquest, 2000).

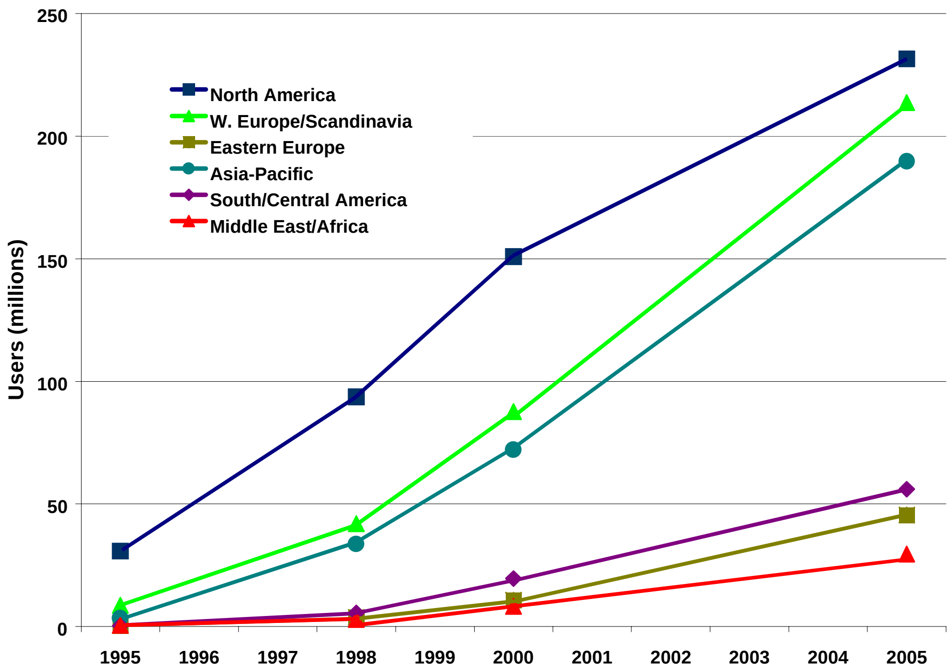

Figure 2. Growth in Adult Internet Users by Region, 1995 to 2005

Corresponding estimates of the number of Internet users per capita by region are shown in Figure 3 (data from Computer Industry Almanac, 2000). In North America, it is forecast that seven out of every ten adults over sixteen will be regular Internet users by 2005, while in Western Europe and Scandinavia this ratio is likely to be five out of ten.

Currently, the highest Internet use per capita is in the Scandinavian countries of Iceland, Finland, Norway and Sweden, but the ratio for the entire region is brought down by lower usage per capita in Southern European countries. Per capita Internet use in France is depressed because of the previous heavy commitment to the separate Videotex Télétel (Minitel) system, but France Télécom has launched a project to provide Internet access via Minitel without use of a PC (OECD, 1998). Per capita Internet use will likely remain much lower in Asia, being projected at only about 50 per 1,000 population in 2005. But the large regional population base will ensure that the total number of Internet users in Asia will eventually rival North America and Europe.

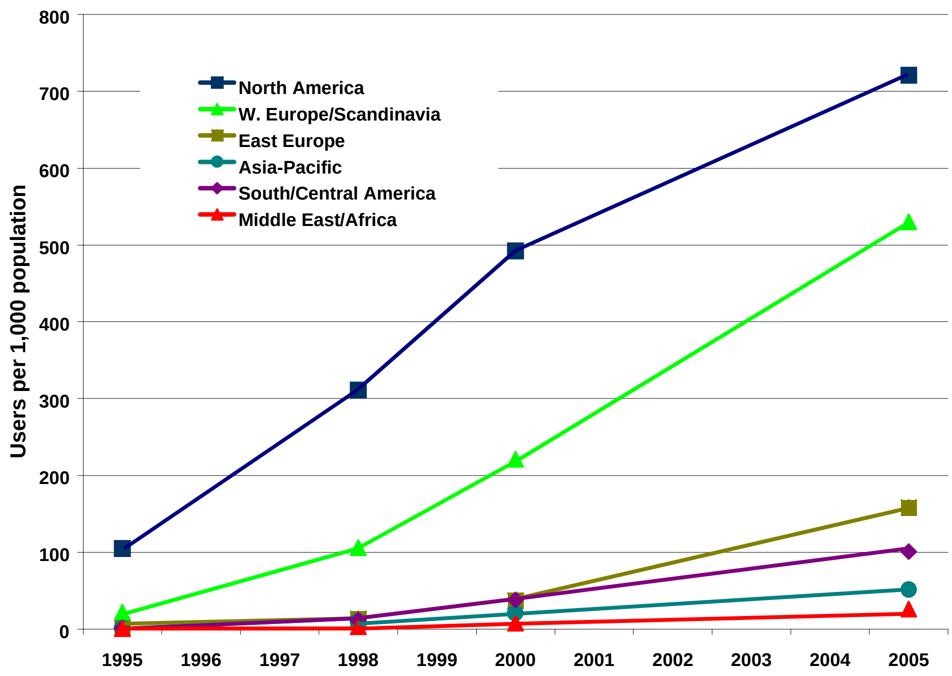

Figure 3. Growth in Adult Internet Users per Capita by Region, 1995 to 2005

Internet connectivity introduces potential equity issues in the information age. In the U.S., it is estimated that 41% of the population has access to the Internet either at home or at work, and an additional 9% of the population have access through schools and libraries (source: Arbitron, 2000). To the extent that individuals are able to improve the quality of their lives by adjusting their activity and travel by using the Internet and related IT, these advantages will be distributed unequally across different groups in the population of most countries. In the U.S., Internet access is a function of economic status, geographic location, age, race, ethnicity, and gender (Castells, 1989, 1996, Ebo, 1998). Research is underway concerning ways in which access can be enhanced (e.g., accessibility for senior citizens: Williamson, 1997 and Blake, 1998; for racial minorities: Hoffman and Novak, 1998; for lower income groups: Moss and Mitra, 1998 and

Robinson, *et al*., 1999; and for women: Ford and Miller, 1996). Travel behavior researchers concerned with inequalities in mobility and accessibility need to monitor the findings from these studies.

The total Internet economy is large and rapidly growing. Table 2 lists the worldwide estimates of revenues generated from Internet-based business by U.S. firms (Barua, *et al.*, 1999). The total world Internet economy is forecast to reach $US 2.3 trillion by 2003 (IDC, 1999). More than half of all revenue is generated by the Internet industry serving itself. However, a substantial portion of the Internet economy in the U.S. is in e-commerce, and this proportion is increasing over time. For purposes of investigating impacts on activity and travel behavior, the e-commerce economy must be broken into two components: consumer (business-to-consumer or residential) e-commerce, and business-to-business e-commerce. The European Internet economy is estimated to be about one-third of the U.S. Internet economy (IDC1999).

Table 2: The Internet Economy - Worldwide Estimates of Revenue for U.S.-based Companies (Revenues in U.S.$ billions)

Layer of the Internet Economy	1st Quarter 1998	1st Quarter 1999	Growth 1998-1999
1. Infrastructure: Backbone providers, ISP, networking hardware and software, PC and server manufacturers, security vendors, fiber optics and line accelerator manufacturers	26.8	40.1	50%
2. Applications: Consultants, commerce and multimedia applications, web development and search engine software, online training and web-enabled databases	13.9	22.5	61%
3. Intermediary: Vertical-industry market makers, online travel agents and brokerages, content aggregators, portal and content providers, ad brokers, online advertising	11.0	16.7	52%
4. E-commerce: E-tailers, manufacturers selling online, fee/subscription-based companies, airlines selling online tickets, online entertainment/professional services	16.5	37.5	127%
Total quarterly revenues (after removing overlaps)	64.0	108.0	68%
Annual revenues (after removing overlaps; projected for 1999)	301.4	507.0	68%

Investment in Information technology is proceeding at a rate that will ensure a secure future for the Internet, even at its present high rate of growth in usage. Most of this investment is being made in the U.S., but the rest of the world, particularly Western Europe, is catching up. In terms of total IT investment worldwide, the top ten countries in 1999 were: (1) U.S., (2) Sweden, (3) Finland, (4) Singapore, (5) Norway, (6) Denmark, (7) Netherlands, (8) Australia, (9) Japan, and (10) Canada.

The next generation Internet Protocol, IPv6 (previously known as IPng) is imminent. IPv6 is designed to relieve problems of address space exhaustion and router table explosion by allowing for growth up to 100 computers per human being, or 10^{15} computers connected by 10^{12} networks (Hinden, 1999). Next generation IP-based (multimedia) networks are being constructed around high speed (2.5 gigabytes or higher per second) backbones (Dècina and Trecordi, 1999).

The Other IT development that might prove to be particularly important for e-commerce, and hence travel behavior, involves the language of the Internet. Presently, most information is transferred using hypertext markup language (HTML) understandable only through human eyes. Some information is also transferred among programs using languages such as CORBA (Common Object Request Broker Architecture), which cannot be read by humans. However, developments are proceeding on a language for the Internet called extensible markup language, or XML. XML is designed to be readily interpretable by both machines and humans. XML encodes information with meaningful structure and semantics that computers can readily understand, while retaining HTML-like properties. XML will provide a framework for intelligent agents and other robotics that will define the second-generation Internet, particularly e-commerce.

Agents (variously called autonomous, automated, intelligent, mobile, or software agents, or software robots or “bots”) are programs that act independently on behalf of their users in furtherance of their users’ interests. This is expected to revolutionize the Internet (Maes, *et al.,* 1999, Glushko, *et al.,* 1999, Wong, *et al.*, 1999). Agent technology is capable of doing for the Internet what graphical interfaces such as Windows and Macintosh did for the PC: provide an effective and friendly user interface (Vulkan, 1999). Agent-based technology is projected to become a $US 4 billion software market by the end of 2000 (source: Ovum, 2000). The anticipated impacts of agents on e-commerce are explored briefly in Sections 3.2.1 (consumer e-commerce) and 3.2.2 (business-to-business e-commerce).

3.3. Mobile Phones and Fusion of Information Technologies

Mobile (portable wireless or cellular) phones are becoming omnipresent. Worldwide, at the beginning of 2000, the number of cellular subscriptions was 470 million, and this is forecast to grow to 1 billion by the end of 2003 (source: Ovum, 2000). Europeans lead the world in mobile phone use, with over 117 million subscriptions (source: Forrester, 2000). The market penetration of mobile phones in the U.S. has lagged behind many other countries (with only 69 million portable phones in the U.S. in 1999), but penetration is nevertheless expected to accelerate and reach 54% of the American population by 2004. Over the past few years, mobile phone technology has evolved from analog to digital voice communication, and a worldwide standard for third-generation digital (3G Wireless) will come online in 2000 through 2002 (source: CTIA, 2000). One billion mobile phone subscribers are forecast worldwide by 2005, but a substantial portion of these phones will have multimedia capabilities (source: Nokia, 2000). If there are a billion mobile phones worldwide by 2005, this will be more than all PC's and automobiles combined.

Multimedia capability ensues when mobile communication shifts from voice-only to a combination of voice and data. Mobile phones and pagers with short messaging services (SMS) are now in common use (with an 11% penetration in Europe). But the major new development is in mobile phones and other held-held devices enabled with Internet access. These devices, generally referred to as smart phones, Webphones, or wireless intelligent terminals, are made possible by the fledgling "Microbrowser" Wireless Applications Protocol (WAP) and third-generation CDMA (code division multiple access) transmission interface technology. In 1999, France Télécom began testing the use of smart phone technology to allow users of its Videtex Télétel system to access the Internet.

It is forecast that the number of Internet-enabled mobile phones using WAP and its successors will soar from 1.1 million at the end of 1999 to anywhere from 21 to 80 million worldwide in 2003 (sources: Dataquest, 2000, In-Stat, 2000, Yankee Group, 2000 and Jupiter Communications, 2000). Even by the end of 2001, it is estimated that 28 million Americans will be using mobile phones for data transfer, 75% of these using SMS and 25% using smart technology (source: IDC, 1999). One source (Dataquest) predicts that shipments of internet-enabled wireless devices will outstrip PC's by 2003.

Improvements in transmission capability required by WAP devices will be supplied by huge infrastructure investments (including many more satellites) and the massive introduction of Bluetooth technology. Bluetooth, named after a fierce 8th century Viking (Harald Blåtand), is an advanced radio technology that is designed to operate in noisy, uncoordinated radio frequency environments, utilizing extremely fast acknowledgement and frequency-hopping schemes and forward error correction. It is anticipated that more than 75% of all handsets shipped in 2004 will be Bluetooth-enabled (source: Dataquest). This technology will help transform the mobile phone into a true multi-purpose wireless communication device.

Another fusion technology, voice over Internet Protocol (VoIP) is also touted as leading to a pivotal reshaping of the communications industry. VoIP will finally bring full multimedia capability to the Internet (Dècina and Trecordi, 1999). It also enables phone calls to travel over the Internet as digital packets. VoIP is now a $US 290 million business, up from $US 130 million last year and is forecast to become a $1.8 billion business by 2003 (source: IDC, 1999). It is difficult to predict what other technologies involving combinations of computers and communication devices lie ahead. There is a great deal of research underway in the field of multimedia communications.

4. POTENTIAL EFFECTS OF INFORMATION TECHNOLOGY ON TRAVEL BEHAVIOR

4.1. Working Arrangements

It is argued here that information and communications technology will in the future affect working arrangements in myriad ways. For purposes of exposition, the following discussion is divided rather arbitrarily into five parts: (1) flexible working arrangements, which includes telecommuting (teleworking), (2) self-employment, (3) contingent and part-time arrangements, (4) teleconferencing, and (5) mobile work.

4.1.1. Flexible Working Arrangements

IT in the form of home computing, the Internet, fax machines and express mail delivery has increased the effectiveness of flexible working arrangements between employers and their employees. There are many quality-of-life advantages of sometimes or always working at home, as described by Shamir and Salomon (1985) and Christensen (1988). Advantages related to activity behavior include enhanced day-to-day flexibility in activity scheduling and the sharing of activities with household members, more opportunities for quality time with family members, and saved commuting travel time.

Telecommuting (or telework) generally refers to formal arrangements between employees and their employers regarding work conducted at home or at a remote center that is more convenient to the employee than his or her main workplace. (Telecommuting can also refer to informal arrangements, but there has been less research on this.) The effects of telecommuting on travel behavior have been extensively studied, largely through the efforts of Mokhtarian and Salomon and their colleagues. Reviews of telecommuting studies are provided by Handy and Mokhtarian (1996b), Mokhtarian (1991)(1997b)(1998), Mokhtarian, Handy and Salomon (1995), Mokhtarian and Salomon (1997), and Nilles (1988). Individual studies are documented in Balepur, *et al.* (1998), Bernardo and Ben-Akiva (1993)(1996), Hamer, *et al.* (1991)(1992), Handy and Mokhtarian (1995)(1996a), Henderson and Mokhtarian (1996), Kitamura, *et al.* (1990), Koenig *et al.,* (1996), Lund and Mokhtarian (1994), Lyons, *et al.* (1997), Mannering and Mokhtarian (1995), Mokhtarian, Bagley and Salomon (1998), Mokhtarian and Salomon (1994)(1996a,b,c) Mokhtarian and Varma (1998), Olszewski and Mokhtarian (1994), Pendyala, *et al.* (1991), Stanek and Mokhtarian (1998), Sullivan, *et al.* (1993), Varma, et al. (1998) and Yen, *et al.* (1998). As discussed by Salomon (1985), Mokhtarian (1990) and Niles (1994), a key issue is the degree to which telecommunications and travel are substitutes or complements in telecommuting behavior.

Telecommuting is appealing to planners and politicians because it implies a reduction in commuting travel at no cost in terms of infrastructure and transportation services. The potential role of new IT in facilitating telecommuting also implies a technological solution to the congestion problem, appeal of which is undoubtedly responsible for generating overly-optimistic early forecasts of telecommuting adoption (Salomon, 1996).

Despite the extensive research on the travel effects of telecommuting, planners do not have a good estimate of the amount of travel that will be generated when saved commuting time is available to a telecommuter. Telecommuting by definition reduces commuting travel (travel from home to work and return) on days on which the telecommuter works at home or at a neighborhood telecommuting center. However, it is well understood that all or part of saved commuting travel time and cost can be converted into new or longer trips for non-commuting purposes, and trips may be required in support of telecommuting activity itself or to replace trip purposes previously linked to commuting (induced demand). These effects are likely to be manifested over the long run and on days other than telecommuting days. Telecommuting opportunities might also influence residential and employment location choices, which in turn affect travel demand (Nilles, 1991, Pendyala, *et al*., 1991). Mokhtarian and Salomon (1996b)(1997) and Salomon (1996) report that most studies have found that the effect of telecommuting on non-commuting trips is statistically insignificant. Additionally, no significant impact on mode choice or residential location has yet been measured. Thus, the consensus so far is that the net effect of telecommuting on travel is an overall reduction in travel time and distance, primarily due to reductions in commuting trips. Mokhtarian and Salomon (1997) argue that this represents substitution of telecommunications for travel. Of course, as with any potential reduction in vehicle miles of travel on congested links of networks, latent demand by persons not engaged in telecommuting is likely to replace some of the travel foregone by telecommuters (Goodwin, 1996; Heanue, 1998). This needs to be studied.

The basic travel behavior question concerns how entire activity patterns are affected by greater temporal and spatial flexibility in work activities. Components of this overarching question include, but are not limited to: (1) How is work travel, broken down into commuting trips and trips for work-related purposes, a function of different types of flexible working arrangements? (2) How do these effects interact with personal and environmental characteristics? (3) How is non-work travel correspondingly affected? (4) How do workers rearrange their work activities to accommodate other activities? (5) Finally, which technologies are most effective in encouraging which types of arrangements, and, in turn, which types of travel patterns? This last question can provide a hook to policies aimed at encouraging sustainable growth (Camagni, et al., 1998, Nijkamp and Ursem, 1998).

4.1.2. Self Employment

IT influences go far beyond telecommuting and other flexible arrangements made between employees and employers. In order to cut costs and increase flexibility in rapidly changing marketplaces, businesses have increased subcontracting and other types of outsourcing, which in turn encourages self-employment (Manser and Picot, 1999). New home-based and mobile IT has improved the effectiveness with which self-employed individuals can communicate with clients, suppliers, and collaborators. Women, in particular, are more than ever choosing self-employment and other flexible working arrangements (Boden, 1999).

Giuliano (1998) reports on important differences between full-time, part-time, and self-employed workers in terms of their commuting patterns and residential and work locations. Additional relevant questions for travel behavior are similar to those posited for flexible working arrangements. Also, we should investigate how individuals change their travel behavior as a result of becoming self-employed for the first time. And how do self-employed workers differ from their employee counterparts, in terms of activity and travel behavior?

4.1.3. Contingent and Part-time Working Arrangements

In some countries, particularly the U.S., new information technology is one of the factors causing increases in the percentage of workers who are engaged in contingent (non-permanent) and part-time work arrangements (Barnasek and Kinnear, 1999; Boden, 1999; Capello, 1994; Manser and Picot, 1999). Advances in IT make it easier for firms to keep track of and integrate the work of non-permanent and non-full-time workers. If part-time workers and full-time contingent workers continue to have shorter commuting times than full-time non-contingent workers, as reported by Giuliano (1998), increases in the relevant size of the part-time and contingent work force could have a moderating effect on peak-period traffic congestion. Giuliano and Gillespie (1997) argue that the greatest effects of IT on travel will be through the “indirect” societal changes involving temporary and short-tenure employment and self-employment, and these effects will far outweigh the influences of telecommuting on travel behavior.

An important factor is the IT economy itself, particularly the Internet portion of the industry. Start-up Internet firms must grow quickly to be successful, and in certain circumstances they must shrink quickly in order to survive. This generates substantial numbers of part-time and contingent hi-tech workers. In addition, the corporate culture of the Internet industry relies on creativity and embraces free-lance (self-employed) professionals. Thus, in the U.S. there are extensive populations of contingent workers in large metropolitan areas and in regions where high-tech firms are concentrated (the so-called silicone valleys, forests, beaches, and hills of the U.S.). Employment of contingent and part-time workers has been traditionally discouraged by most Western European governments and by the E.U., and this difference in labor laws is often cited as one factor in Europe’s lag behind the U.S. in terms of the Internet economy.

4.1.4. Teleconferencing

Another major work-based interaction between travel and telecommunications is teleconferencing (or videoconferencing). Interactive communications technology allows workers within the same organization and at different organizations to engage in meetings without having to travel to a common location. Following telecommuting, this is one of the most researched topics in travel demand modeling (Bennison, 1988, Button and Maggi, 1994, Plaut, 1997, Salomon, *et al.*, 1991).

The consensus to-date is that teleconferencing has little overall influence on business travel. However, until now, teleconferencing technology has been relatively awkward and expensive. IT developments of the class discussed in Section 2.3 will facilitate more attractive and effective videoconferencing. VoIP (voice over Internet Protocol) and related technology will greatly extend videoconferencing connectivity. This makes it difficult to extrapolate from previous studies of experiences with old technology. Research involving impacts of IT become obsolete quickly. On the other hand, teleconferencing has proven to be a poor substitute for face-to-face communication in many applications, and IT might not change those results. Teleconferencing will need to be studied again in the future.

4.1.5. Mobile Working

Closely related to flexible working arrangements is the issue of the impact of mobile IT on work that takes place away from the usual workplace(s) or home (Mokhtarian, 2000). Due in large part to today's mobile phones and portable SMS (email) and fax devices, many people maintain mobile offices. Others carry on work while commuting between home and their office or remote work site. Commuters can also use mobile communication devices to make more efficient use of their travel time by conducting business and coordinating activities with household members and friends. For the rest of the population, the downside to mobile working is the hazard to road safety caused by drivers engaged in mobile phone conversations, and the disruption to our peace and quiet caused by loud mobile phone conversations in public places, particularly in public transport conveyances and on station platforms. Hopefully, this will be attenuated by new laws and ordinances, and by improvements in manners.

Smart mobile phones and handheld wireless Internet devices will increase the efficiency and pleasure of working while on the move. We can safely assume that mobile workers are presently using telecommunications to optimize their activity and travel schedules, and future IT developments will improve their ability to do so. Mokhtarian (2000) agues that we need to study how this affects workers' activity and travel patterns. By collecting appropriate data on the use of mobile communication devices, together with corresponding data on activity participation and travel of mobile workers, we should be able to classify types of telecommunication activities in terms of replacement, generation, and management of specific types of activity and travel behavior. Such a classification scheme was used by Claisse and Rowe (1993) in a study of the effects of domestic telephone calls on mobility. Zumkeller (1996)(1997) and Mokhtarian and Meenakshisundaram (1999) demonstrate how communications data can be collected for such studies.

4.2. Electronic Commerce

Estimates of e-commerce as a proportion of present business vary greatly, depending upon how e-commerce is defined. However it is defined, most e-commerce occurs between businesses. Probably about 20% of all e-commerce in the U.S. in 1999 can be classified as consumer (business-to-consumer or residential); the rest is e-commerce between companies (business-to-business). This presentation deals primarily with consumer e-commerce. Business-to-business e-commerce and its consequent influences of IT on freight transportation are covered by another resource paper at this conference (Regan and Garrido, 2000). Business-to-business e-commerce is discussed in order to place consumer e-commerce in its proper perspective.

Growth curves for *worldwide* e-commerce, separated into consumer and business-to-business, are shown in Figure 4 (based on data from IDC, 1999). This Figure shows $US 1.3 trillion in e-commerce revenues by 2003. While this estimate has been extensively cited (e.g., Financial Times, 1999), other forecasts are more optimistic. Another industry observer (Boston Consulting Group, 2000) predicts that one-fourth of all U.S. business-to-business purchases will be online by 2003, and at the time business-to-business e-commerce will reach $US 2.8 trillion in transaction value. Some reasons for these discrepancies are explored briefly in Section 3.2.2.

4.2.1. Consumer E-commerce

The recent growth in consumer e-commerce on the Internet has been phenomenal. Limited e-commerce services have been available since the 1980's for users of Videotex systems, such as France's Télétel (using Minitel terminals). Now, with a basic Internet-enabled home computer or other Internet access device, consumers all over the world are introducing themselves to an extremely wide variety of e-commerce services. In 1999, it is estimated that 7 million households in the U.S. made their very first online purchases. It is also estimated that more than 17 million U.S. households shopped online by the end of 1999, and the forecast is that 49 million U.S. households will shop online by 2004 (source: Forrester, 2000). At the present time, in early 2000, 10% of U.S. households shop online (Ernst and Young, 1999).

One industry observer (IDC, 1999) estimates revenue from consumer e-commerce in the U.S. to be $US 20 billion in 1999, up dramatically from $US 4 billion in 1997 and $10 million in 1998. Other sources (e.g., Boston Consulting Group, 2000) estimate even bigger consumer e-commerce revenues, on the order of $US 36 billion for 1999. But all agree on substantial growth. A conservative projection is for $US 54 billion in 2002, representing a compound annual growth rate of almost 60% (source: IDC, 1999). Another estimate has U.S. consumer e-commerce at $US 184 billion by 2004 (source: Boston Consulting Group, 2000). The rest of the world is lagging behind the U.S., but regions such as Europe are catching up rapidly. Forecasts vary partly because a major component of growth in is in terms of first-time buyers, and it is not well understood how the repeat buyer will behave over longer periods of time. Also, early adopters still make up a substantial portion of the all e-commerce, and it is not well understood how later adopters will conduct their business. Nevertheless, almost all industry observers feel that growth will almost certainly accelerate over the next few years.

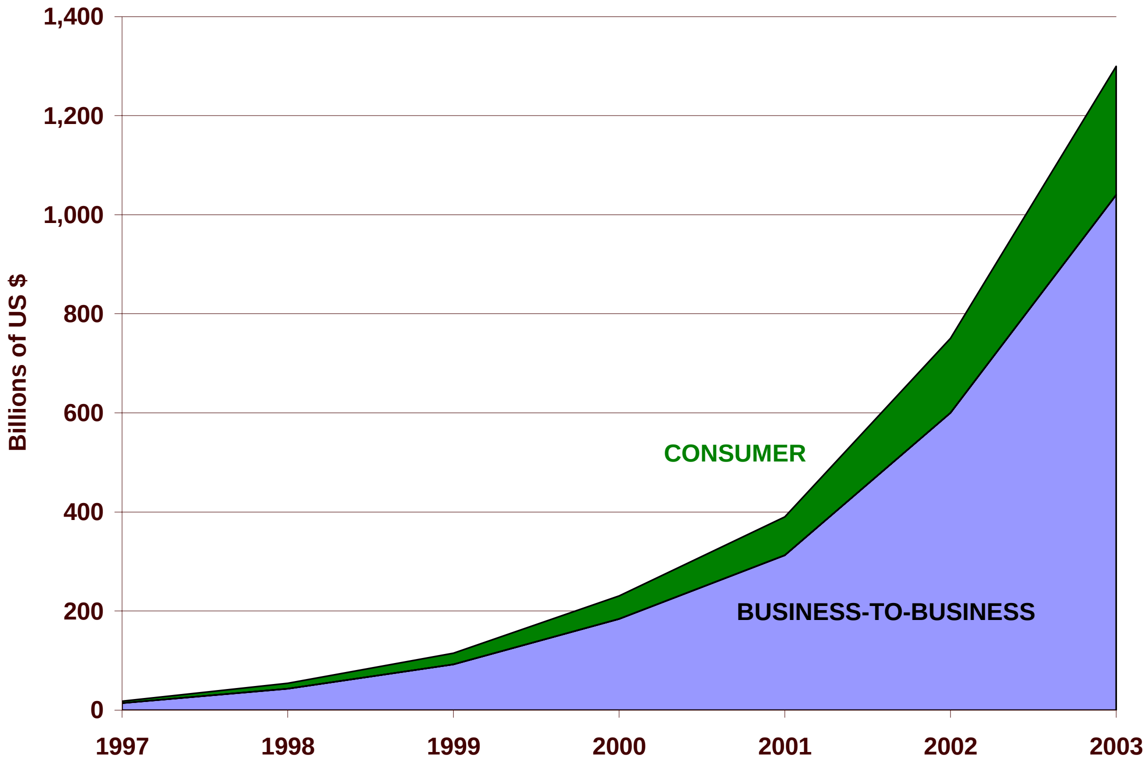

Figure 4: Growth in Worldwide E-commerce Revenues

The major reasons for the expectations of accelerating growth in consumer e-commerce are the imminent advances in information technology discussed in Section 2. In large part, these technologies are being driven by aspirations to make e-commerce more attractive and effective. Some of these new technologies include connections to a higher-speed multimedia Internet through television set-top boxes and handheld Internet devices. Perhaps most importantly, the next-generation Internet will incorporate VoIP (voice over Internet Protocol), XML (extensible markup language) and intelligent agents (software "bots"), as discussed in Sections 2.2 and 2.3. These advances will allow E-consumers to send out intelligent agents to find best values and new opportunities (Vukan, 1999 Maes, *et al.,* 1999, Glushko, *et al.,* 1999). The advances will also allow personalized human-assisted e-commerce (Dècina and Trecordi, 1999). Future e-commerce Websites might also employ virtual reality effects to make shopping a more realistic and exciting experience (Batty, 1996, 1997a, 1997b). Made more attractive and easy, consumer e-commerce might well become an integral part of daily activity patterns for millions of people worldwide. Travel behavior researchers need to recognize this, and we need to take immediate steps to begin to understand its consequences.

Currently, the major sectors of consumer e-commerce are books, software, music, travel (e.g., airline tickets), hardware, clothing, and electronics (source: Cyber Dialogue, 1999). As with all retail commerce in the U.S., online retail sales (including travel) peaks at the Christmas holiday period. To provide a feel for the type of online shopping that occurred during the most recent (1999) peak period, Table 3 lists the most popular holiday season Internet sites (Media Metrix, 2000). These represent the largest e-merchants. In the near future, smaller e-merchants are expected to band together to form virtual malls, with portals to varieties of e-retailers, for "one-stop" Internet shopping.

Table 3: Top 25 E-commerce Sites for Five-Week Holiday Shopping Season, November 14 through December 26, 1999

Rank	Site	Unique Visitors	Rank	Site	Unique Visitors
1	Amazon.com	5,693,000	14	bonzi.com	674,000
2	ebay.com	4,073,000	15	americangreetings.com	638,000
3	etoys.com	1,662,000	16	beyond.com	623,000
4	Barnsandnoble.com	1,522,000	17	shopnow.com sites	619,000
5	Toysrus	1,486,000	18	ticketmaster	597,000
6	buy.com	1,427,000	19	jcpenny.com	594,000
7	cdnow.com	1,416,000	20	dell.com	582,000
8	Egreeetings.com	1,116,000	21	overstock.com	549,000
9	Expedia	1,019,000	22	compaq.com	522,000
10	Travelocity.com	934,000	23	shopping.com	515,000
11	Egghead.com sites	900,000	24	columbiahouse.com	513,000
12	kbkids.com	799,000	25	priceline.com	500,000
13	Bmgmusic.com	782,000			

There is also developing e-commerce in groceries and household goods. Industry observers disagree on the immediate potential for this sector, with estimates of revenues for 2000 in the U.S. varying from around $US 1-2 billion (source: Jupiter Communications, 2000) to $US 6 billion (source: Yankee Group, 2000). Even if online grocery shopping grows to about $US 11 billion by 2003, this will still only be 2% of the total grocery market (source: Forrester, 2000). Restricted geographic location, high development and maintenance costs of online inventory display, and high delivery costs are often cited as factors impeding the growth of grocery e-commerce. E-merchants in this sector are attempting to establish one of two types of markets: household replenishment or specialty luxury items (sources: Forrester, 2000). Online shopping for groceries and household goods can be particularly important for activity and travel behavior, because this activity is much more repetitive than other types of shopping.

It is difficult to estimate how much of online consumer sales would have occurred at "bricks-and-mortar" businesses. One e-commerce industry source (Jupiter Communications, 2000) estimates that most online sales are shifted "from bricks to clicks," and only a minority of online sales are shifted from over-the-phone catalog sales; thus only 6% of online sales would not have occurred otherwise. Many online shoppers also use the Internet as a research tool, to compare prices and features. Another industry observer (Cyber Dialogue, 1999) estimates that Internet shopping influenced $US 51 billion in offline spending in 1998. Also in 1998, it is estimated that more than five million new car buyers and 26% of used car buyers in the U.S. pre-shopped on the Internet (J.D. Power, 1999).

One advantage that bricks-and-mortar merchants have is that access is free at their stores, while most online consumers must pay to access the Internet. That is changing. In Europe, the Tesco and Waitrose grocery chains offers free Internet access to their club members. (However, telephone calls are still metered in the U.K. and generally elsewhere in Europe, so free Internet provision does not mean free Internet access, as it usually does in the U.S.) In the U.S., it is anticipated that major bricks-and-mortar retail chains will soon establish their presence online bundled with free Internet access. Two huge partnerships are Walmart and America Online (AOL), and Kmart and Yahoo! It is even expected that e-merchants will soon be offering free Internet appliances (smart phones, PDAs, and inexpensive PC's).

Hardly any e-commerce observer seriously believes that online shopping will replace a large proportion of shopping sojourns at bricks-and-mortar businesses in the foreseeable future. Shopping is often linked together with other activities, and there are many other reasons for shopping besides the ultimate purchase of a bundle of goods (Gould, 1998, Koppelman, *et al.,* 1991). Shopping also involves recreation, social contact, search for new opportunities and enjoyment of being outside, or being in an urban or village center environment.

On the other hand, this substantial shift of consumer purchases from brick-and-mortar businesses to e-commerce (from "bricks" to "clicks") has to have some pronounced affect on travel and activity behavior, and that effect will surely increase over time. In 1995, it was estimated that shopping trips comprised one out of every five person trips and one out of every seven person miles traveled in the U.S. (NPTS, 2000). If, for each online shopper, only a few sojourns per year at bricks-and-mortar merchants are now replaced by e-commerce, the number of trips affected worldwide is relatively large. As online shopping becomes more accessible and attractive due to imminent advances in IT, and as Internet users become comfortable with online shopping, the individual impacts on activity and travel behavior will probably increase, while at the same time the number of online shoppers is increasing exponentially. Within a couple of years, the effect overall effect could well be huge.

Travel behavior researchers are just beginning to explore the consequences of e-commerce (Gould, 1998, Gould and Golob, 1997, 1999, Kilpapa, *et al*., 2000, Marker and Goulias, 2000, Martens and Korver, 2000). These more recent studies are guided by a series of earlier works of the Northwestern group that predated the Internet as we know it today (Koppelman, *et al.,* 1991, Salomon, 1985, 1986, 1990 Salomon and Koppelman, 1988, 1992, Salomon, et al., 1991 Salomon and Schofer, 1988). But it is difficult for travel behavior researchers to keep up with the pace of IT development. Hence, we run the danger that the conclusions from our studies of consumer e-commerce are outdated in that they are relevant to virtual opportunities that are obsolete before the studies are completed.

Because trips for household replenishment make up a large portion of all shopping trips, much of the travel behavior research has concentrated on online grocery shopping (Gould, 1998, Gould and Golob, 1999, Kilpala, *et al*., 2000, Marker and Goulias, 2000). Also, most of other retail e-commerce in the U.S. is concentrated in the short holiday shopping season, and transportation planners have never been very concerned about seasonal congestion. The marketplace for online sales of groceries and household goods has been characterized by many failures and few successes (Cairns, 1996), but e-merchants are persevering in their search for new markets. In the U.K., all but one of the major supermarket chains have embarked on e-commerce, making home delivery available to almost everybody living in London (inside the M25) and other major U.K. cities. The Waitrose chain is marketing a service that delivers free to offices, as long as at least 300 employees in a company or building sign up. U.K. specialty food shops are also going online, including the nation's oldest cheesemonger (Paxton and Whitfield) and some of the largest purveyors of both gourmet and organic food items. Travel behavior research by Gould and Golob (1997) (1999) and Gould (1998) has pointed out that one prime market for online grocery and household goods shopping is likely to be fully employed female heads of households, who typically have very busy activity schedules. They forecast that some of the travel time saved if this segment eliminates some shopping trips will be converted to travel for other purposes, but most of the saved time will be converted to activities at home. Of course, freight travel is also generated through the home delivery of online purchases.

With projections of 50 million households in the U.S., and possibly an equal or greater number in the rest of the world, shopping online by 2004, even relatively minor impacts on activity and travel patterns will aggregate substantially. As travel behavior researchers, we need to begin understanding how time spent in conducting shopping and personal business online compares to the traditional alternatives. We need to determine, for different segments of the population, which activities are telecommunication substitutes and which are complements, with the objective of quantifying impacts on travel times and distances (Mokhtarian, 2000). In addition, we need to quantify the demand for freight transportation involved in home deliveries.

4.2.2. Business-to-Business E-Commerce

The vast market for business-to-business e-commerce is driving many of the technological developments reviewed in Section 2.2.2. In particular, the XML language for Web pages and intelligent agents (specifically Java-based agents), are designed to serve future online business needs. Up until the present, much of business-to-business e-commerce has occurred on private specialized networks using what is called EDI (electronic data interchange). EDI functions will likely be integrated within the Internet, as a result of XML and other Internet enhancements (Glushko, et al., 1999). Estimates of EDI transactions may or may not be included as part of all business-to-business e-commerce (EDI is included in Figure 4 data). Including EDI transactions, one source (Boston Consulting Group, 2000) estimates that online business-to-business transactions in the U.S. amounted to $US 671 billion in 1998, $US 92 on the Internet and $US 579 billion using EDI on private networks. By 2003 it is projected that the Internet's share will dominate the EDI's share of more than $US 2 trillion in online transactions. The following 1999 to 2003 growth factors are projected: In North America, e-commerce transactions will increase from 7% to 24% of all business-to-business transactions; in Western Europe the growth will be from 3% to 11%; in Asia/pacific it will be from 2% to 9%; and in Latin America it will be from 2% to 7% (source: Boston Consulting Group, 2000).

Soon companies will be using computer-interpretable XML forms for publishing product catalogs, placing orders, making reservations, and scheduling shipments. Intelligent agent with proper authorization will be able to obtain price lists, inventory reports, and schedules, and will even be able to negotiate with other agents to form and reform strategic coalitions to bid on contracts and leverage economies of scale (Glushko, et al., 1999, Maes, at al., 1999). The savings in operating costs are projected to be substantial, on the order of $US 1.25 trillion worldwide by 2002 (source: Giga information Group, 2000). Implications of e-commerce for freight transportation are addressed by Regan and Garrido (2000).

4.3. Other Teleservices, Especially Telemedicine

In addition to shopping, people will increasingly use the Internet for services such as banking, dealing with governmental agencies (for example, to gather information, register for services, pay taxes, or obtain permits), making travel arrangements, and many other personal business activities. In particular, telemedicine (online medical services) is becoming a very important part of medical practice (Bashshur, *et al.*, 1997, Viergas and Dunn, 1998). In the U.S., it is forecast that 33.5 million adults will use the Internet to find health and medical information in 2000, searching among the over 15,000 Internet healthcare sites (source: Cyber Dialogue, 2000).

The Internet provides a way of extending medical services to people who, for reasons generally associated with location or mobility, are unable or unwilling to visit traditional office and hospital sites for treatment and diagnosis. Telemedicine can be particularly important for remote emergency situations and for hospice care (Doolittle, et al., 1998), as well as for the dispensing of drugs and other pharmaceutical products. Future IT developments in television Internet interface (Valero, et al., 1999) and intelligent agents (Della Mea, 1999) are particularly well suited to telemedicine, indicating that this area has substantial growth potential, despite resistance among many physicians and healthcare providers (Bickert, 1999). Development in telemedicine will probably have only infrequent effects on the activity patterns of most people, but these developments are likely to have profound effects on the activity patterns of some elderly and chronically ill people.

4.4. IT and Education

Information technology is revolutionizing higher education (French, *et al.,* 1999, Latchman, *et al.,* 1999, McCormack and Jones, 1998, Porter, 1997, and Trow, 1997). In addition to being a source of information and a teaching tool in the conventional classroom, Internet access allows off-campus study for full-time and extension students at colleges, vocational schools, and other institutions. Higher education is proceeding rapidly into the realms of both telecommuting and teleconferencing. Studies of educational IT developments might be used to predict broader IT influences on workplace environments. The activity and travel behavior of students enrolled in college and continuing education programs will be very much affected by IT developments.

At all levels of education, the use of the computers and Internet serves as a training ground for Internet use in other aspects of daily life. Cohorts of children and young adults who are versed in IT use in school will assuredly make greater use of IT in later life, when compared to cohorts of older people who were not exposed to IT as part of their formal education. This is one of the reasons behind estimates of accelerating levels of e-commerce and other teleservices.

4.5. IT and Traveler Information

Future IT should greatly enhance the potential for effective and user-friendly traveler information. ATIS (Advanced Traveler Information Systems) will be able to take advantage of elegant new Internet technology developed not for the transportation market, but for the much larger market of business-to-business e-commerce. These Internet (Web-based) systems could replace existing technology developed directly for ATIS, technology that often doesn't work as advertised or is found by potential users to be ungainly and unattractive. The next generation of the Internet will support intelligent agents that operate on computer-readable XML Internet information content, as discussed in Sections 2.2.2 and 3.2.2. It will be relatively straightforward to design agents and XML Websites containing real-time information on network performance levels, so that agents can interrogate the network sites and report back on the state of travel conditions. A viable extension is for the traveler's agent to recommend alternative trip routing and timing. Hand-held Internet devices (Section 2.3) will allow travelers to access Web pages and receive reports from smart agents at sites away from home.

Specialized applications will undoubtedly include providing access information for handicapped travelers, tourists, and anyone with unusual requirements. IT advancements will also improve the efficiency and attractiveness of mobility-sharing programs. Car sharing has flourished in Europe, where in 1999 there were over 200 organizations in 450 cities involving over 130,000 participants (Sperling, Shaheen and Wagner, 1999). Most car sharing involves use of general-purpose automobiles, but some programs involve sharing cars for access to public transport and sharing of alternative-fuel vehicles, or both (e.g., the CarLink Program, which provides cars for access to a rail transit station in the San Francisco Bay Area). IT can facilitate reservations and billing and can allow clients to check on the real-time availability of vehicles at any given location.

ATIS is only one portion of so-called Intelligent Transportation Systems (ITS) that will benefit from near-term advances in IT. Traveler behavior will surely be affected, and studies such as those of Polydoropoulou, *et al*. (1994), will need to be repeated to test the behavioral effects of travelers easily obtaining more accurate and accessible information concerning route, destination and trip timing. Regarding shopping activities, previous studies (e.g., Kraan, *et al.*, 2000) should be expanded to include online shopping options that do not involve travel at all.

The groundwork for studying the effects of traveler information on travel behavior has been laid in the studies reviewed by Golledge (1997) and Mahmassani (1999). In most cases, these studies need updating to extend their findings to capture the effects that future higher performance ATIS will have on activity and travel behavior. The best way to do this in advance of implementation is to use stated choice experiments to expand the attributes of present information, preferably in combination with revealed preference data available through evaluation of a simpler ATIS project implemented using existing technology (Bates, 1998, Hensher, 1994 and Louviere, 2000).

5. POLICY IMPLICATIONS

Planners and policy makers should not miss the rich opportunities presented by IT. It is highly likely that many persons will make use of telecommunications to either eliminate certain types of distasteful travel, or to reschedule and reroute trips to less congested times and places. People have proven to be very ingenious in avoiding congestion and other psychological and economic costs associated with travel (generally being more ingenious than their travel behavior modelers). For instance, consumer e-commerce must be reducing peak holiday period congestion at shopping malls and on commercial streets in the U.S., but we have no reliable measure of this impact. The incidence of contingent, part-time and self-employment, to some extent increased by IT developments, must be reducing peak commute travel, but again we have very little quantifiable evidence of this impact.

Perhaps partly because it is considered a “non-problem,” policy implications of IT impacts on travel have received little attention. Only telecommuting has been looked upon as a means of reducing travel, often with unrealistic expectations (as pointed out by Salomon, 1996 and 1998). If travel behavior researchers can identify which technologies are most effective in reducing travel without undesirable side effects, this should be of great value to planners and policy makers, even if they have no appreciation of that value at the present time.

In terms of the built environment, planners and policy makers need to be aware of the potential effects of e-commerce on the vitality of commercial areas (Batty, 1996, 1997). The vitality of neighborhood stores may well depend in part of whether such stores can compete with large chains in terms of online access and delivery services. Gould and Golob (1999) argue that one way in which neighborhood stores, particularly those in the vicinity of public transport stations in residential communities of large metropolitan areas, can take on a new life as pick-up locations for food items and other household goods ordered online during the day by workers. Architecturally, there is even a new movement to design “cybrid” shopping environments, in which a commercial building and a Website is viewed as a single package, creating resemblances between real and digital environments that can help employees and shoppers alike find products and services easily (Novitski, 1999).

The virtual accessibility supplied by the Internet can be most appreciated by persons with low levels of conventional accessibility. Presently, the highest Internet use per capita is in countries with either long, dark winters (e.g., Iceland, Finland, Norway, Sweden and Canada), or with isolated rural communities (e.g., parts of Australia, Canada and the U.S.). New demand for connectivity is likely to come from isolated areas of developing nations. In addition, social benefit can accrue from extending virtual accessibility through Internet connectivity to handicapped, elderly and economically disadvantaged populations.

Most all modern IT developments are market-driven. Government intervention is not needed, and, importantly, not desired. However, that does not mean that regional and local government planners and policy makers should not be concerned about the impacts of IT on the accessibility of population groups, on land use, and on the timing and location of flows on their transportation networks.

6. RESEARCH FRAMEWORK

6.1. Time-Space and Virtual Accessibility

We need to look at the entire activity pattern of an individual, and the interrelated activity patterns of multiple individuals in a household to understand how telecommunications affects travel behavior. Engaging in telecommunications is an activity itself, just as travel is. However, incorporating telecommunications in our activity paradigms requires that we modify our views of time and space. Just when activity modeling is rediscovering the usefulness of the time-space prism concept originally proposed by Hägerstrand (1970) (1975), the concept itself must be updated to account for telecommunications. Time-space prisms can be used to depict the activity locations that are accessible to an individual within a given time period by using projections to the physical plane from the time dimension. The accessible area is defined by the individual’s present location, travel speeds in all directions, and the time needed to perform the activity. The type of activity can be recorded on the time axis, allowing daily activity patterns to be traced in time and space. Now, however, distance and its associated time and cost can no longer be viewed as the singular impediment to conducting an activity at a remote location. Many activities can now be conducted using telecommunications devices. This has been true ever since the advent of the telegraph, and later the telephone.[3] Now however, shopping, personal business, and work can be electronically performed using visual media such as the Internet from home and from remote locations using new types of mobile telecommunication devices.

To this time-space representation, we should now overlay virtual accessibility to activities that can be performed electronically by persons without changing location. Insights on how to accommodate virtual accessibility can be gained from investigating the time-space concept and the definition of accessibility itself.

Hägerstrand (1970) defined three time-space constraints that can be adapted to the modern world of IT. First is the coupling constraint, which describes a person's commitments to be at certain places at certain times. This is one constraint that is certainly subject to modification due to flexible working arrangements. Activities previously subject to coupling constraints might also be satisfied by replacing personal contact with telecommunications, if a person feels that the activity requires only information and not his or her physical presence. Learning and experience can easily change a person's strength of commitment to coupling constraints (e.g., discovering whether use of a mobile phone is a satisfactory replacement for making a trip to talk with someone in person). Axhausen (1997) argues that feeling and perceptions regarding coupling commitments should be collected as an integral part of activity surveys. We need empirical data to determine which activities people consider to be physically and electronically substitutes, as well as which activities they consider to be physical and electronic complements.

Second is the capability constraint, which captures the ability of a person to overcome spatial separation given the resources available at any point in time. One obvious factor affecting capability is the presence or absence of a vehicle such as a car or bicycle. Other factors, such as the ability to use public transport, are based on knowledge and experience which varies from person to person (Axhausen, 1997). Now we must introduce factors affecting telecommunications capability, such as connected computers and other Internet appliances at home and work, and mobile phones and handheld Internet devices at remote locations. Once again, knowledge about what can be accomplished using such information technology is critical. Demand models need to be sensitive to perceptions of accessibility, and survey instruments need to be designed to elicit perception data.

Finally, Hägerstrand's (1970) third constraint involves authority, which defines time-space zones of opportunity and exclusion, including performance schedules and opening hours. Here again is another metric in which to capture opportunities presented by information

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[3] For an historical study of interactions between travel behavior and new communications technology, see de Sola Pool (1983) and de Sola Pool (1977).

technology. People who are cognizant of e-commerce opportunities might engage in online shopping or personal business at times when bricks-and-mortar businesses are closed. Again, perception of capability is as important as actually having access to telecommunication devices.

In terms of movements through space-time, the duration of the activity will generally be different depending upon whether the activity is performed by traveling or by telecommunications. Suppose a person chooses to perform an activity by remaining at a given location and using telecommunications (mode “A”), rather than by travelling to a different location and physically performing the activity (mode “B”). He or she will gain the saved travel time, and will either gain or loose activity performance time, depending on whether it is quicker or slower to perform the activity by mode A or B. The net gain in time (which could be negative) is the difference between the total travel and activity performance times by the two modes. Total travel and activity duration time for the rest of a person’s activity pattern might either increase or decrease, depending on how a person chooses to allocate the net gain in time, and how he or she is able to link other activities. It is apparent that interactions involving travel telecommunications need to be viewed in a context of activity patterns over multiple days.

Information technology also dictates that travel behavior researchers revisit their definitions of accessibility. Geographers define accessibility to be a measure of the strength and extensiveness of spatial relationships between opportunity seekers and relevant opportunities. Level of accessibility for an opportunity seeker is a function of (1) the total number of relevant opportunities, (2) the spatial distribution of these opportunities, (3) the spatial location of the individual, and (4) the individual’s ability to overcome spatial separations. Shen (1999) (2000) argues for dividing opportunities into three mutually exclusive types for purposes of measuring accessibility: (a) opportunities that can be accessed only through telecommunications and are thus available only to persons with telecommunications capabilities, (b) those that can be accessed either by transportation or by communications, and (c) those that can be accessed only by transportation (i.e., those that require the commitment of physical coupling). IT should be viewed together with the transportation system as a form of spatial technology that influences accessibility (Coucelis, 1995,1996).

6.2. Modeling Technology Adoption and Telecommunication Choices

We will also need to develop analytical tools to forecast individual and household choices of information technology, particularly choices of home-based and mobile Internet communication devices. This the travel behavior field is eminently able to do, with our sophisticated choice modeling methodology (reviewed at this conference by Brownstone, 2000). Moreover, we have the capability to use stated choice methods to extend choice models estimated on actual (revealed) choices to levels of attributes unavailable in existing choice sets (as reviewed at this conference by Louviere, 2000).

Personal choices of activity patterns will become ever more intertwined with choices of information technology. Even in our current travel demand models, where IT is not considered, we often need to recognize that availability of choice alternatives is dependent upon access to mobility resources (e.g., car availability or public transport season tickets) and access to information (e.g., knowledge about public transport routes and schedules, or knowledge about alternative routes). In the new world of IT, activity choice alternatives are a function of access to information technology (e.g., home-based or mobile internet connectivity) and knowledge about how to use the technology for activity scheduling. This mutual causality could be captured by joint models of demand for IT technology and activity patterns, because activity patterns are a function of IT availability, while demands for IT are probably a function of demand for certain activity patterns. Similar joint models have been formulated for car ownership and activity demand (e.g., Golob, 1998).

Household decision making regarding information technology is similar in some ways to household decision making regarding automobile ownership. They both deal with shared household resources, but the choice object is typically used most by only one household member. Mobile communication devices are sometimes shared but often used almost exclusively by one household member, so generally decision making for this technology can be approached an individual basis, with household parameters. When we are addressing choices involving technology that is well entrenched at the time, such as PC's with modem Internet connections or cellular phones today, we can probably collect revealed preference data using random samples. In cases of advanced technologies, such as handheld Internet devices, we will need to employ choice-based sampling.

We should expect high degrees of population heterogeneity in all technology choice models, due to strong age and lifestyle cohort and spatial effects. Such heterogeneity might be captured by interaction terms involving situational variables (such as age group, income, occupation, and location dummies) and choice-specific constants and attributes of the choice alternatives. To the extent that interaction terms fail to capture this heterogeneity, we will need to use more complicated choice models such as random-coefficients (mixed) logit and probit models (Bhat, 1997, Brownstone, 2000).

Choices of telecommunications activities can be integrated into activity-based models. Examples of modeling frameworks that are conducive to extensions to virtual accessibility include, but are not limited to, Ben-Akiva and Bowman (1998), Bhat and Misra (1999), Bowman and Ben-Akiva (1997b), Golob (2000), Golob and McNally (1997), Kitamura (1984), Lu and Pas (1999), Mokhtarian (1998), and Yamamoto and Kitamura (1999).

There is also a need for exploratory data analyses of time use related to telecommunications. Sociologists have documented extensive descriptions of general time use (e.g., Robinson, 1977, Robinson and Godbey, 1997, Robinson*, et al.*, 1997, and Szalai, 1973), and travel behavior researchers have enhanced such descriptions in order to focus on travel as a special type of activity (e.g., Kitamura, *et al.,* 1992 and

Levison and Kumar, 1995). Now we need to focus on both travel and telecommunications within the complex of time use for all other activities. Initial descriptive research of this type is provided by Lee (1999), Massot (1997), Mokhtarian (1990), and Zumkeller (1997). A useful approach is to segment households according to access to information technologies and to compare activity and travel patterns of the segments, controlling for demographic and socioeconomic variables, in a manner similar to comparing for different levels of car availability (e.g., Golob, *et al.,* 1996). Market research firms serving the IT industry constantly produce statistics about telecommunications use, particularly Internet use (e.g., Ernst and Young, 1999). The results regarding demographic and spatial trends in general telecommunications use can be useful to travel behavior researchers setting up studies of impacts on travel behavior.

6.3. Data Needs

6.3.1. Household Travel Surveys

Household travel surveys have evolved from trip-based to activity-based (Lawton, 1997). Activity-based surveys are necessary for the study of telecommunications and travel interactions. However, most household travel surveys collect very little or no data on in-home activities. The agencies that fund these surveys (the metropolitan or regional planning organization, or the state, provincial, or federal agency) are generally not focussed on telecommunications. Their concern remains with trip making, and activities are there to better understand the reasons for a trip. The collection of in-home activities and telecommunication activities both in- and out-of-home has been judged to be too costly in terms of response burden and consequent increase in nonresponse bias and data collection expense. Recent guidelines have been prepared for household travel surveys (Griffiths, *et al.*, 2000) and for travel demand forecasting (Bhat and Lawton, 1999), and both documents barely mention telecommunications. Telecommunications is apparently not registering on the radar screen of the planning community at the present time. This is quite likely to change, and practitioners will come to realize that most household travel survey data collected to date will be of little use in forecasting impacts of telecommunications on travel.

It is not difficult to add in-home communication activities to household travel surveys, as demonstrated by Zumkeller (1996, 1997). Collection of the communication part of a comprehensive activity survey is demonstrated by Claisse and Rowe (1993) and Mokhtarian and Meenakshisundaram (1999). Communication activities should be registered in terms of their type, purpose, duration, location, and send or receive mode. Types can be broken down into face-to-face meetings, transfer of physical objects (by hand delivery, mail or package delivery), and telecommunication. The telecommunications subset at the present time includes phone calls, faxes, emails, and Internet contacts, the latter being subdivided according to the nature of the contact (e.g., information retrieval versus transaction).

In terms of personal and household data, in addition to the usual mobility data on car ownership, parking permits, and public transport season tickets, we need to know what access individuals have to various information technologies. These should include fixed and mobile PC's with Internet access, including small devices, such as personal digital assistants, and wireless devices, such as cellular phones and handheld Internet devices. For household members in the work force, including self-employed individuals, we need to know the details of their working arrangements: their work schedule, their work locations, whether the present working arrangements are permanent or not, and what telecommunications and other job-related equipment or facilities they have at their home or remote work site.

6.3.2. Internet Surveys

Internet usage surveys are common in the Internet industry. One ongoing survey to monitor Internet usage consists of a panel of 3,000 persons who access the Internet at home and at work (Coffey, 2000). There are other similar panels. Typically, respondents chosen at random are asked to install software that will automatically monitor their computer usage. The software is also used to "pop up" and record who in the household (or at a workplace) is using the computer during a session. There are also Internet surveys in which users log onto a survey Website and complete a questionnaire (e.g., VLAB, 1997). Internet survey software is readily available (e.g., Perseus, 2000).

In travel behavior research Internet surveys represent choice-based sampling of a new kind. We are familiar with the statistical and practical issues involved in sampling based on travel mode (e.g., transit on-board surveys) and destination or route (journey intercept surveys). While some have dismissed Internet and other multimedia survey methods as being inappropriate for general-purpose household surveys until there is more widespread household connectivity to the Internet (Griffiths, Richardson and Lee-Gosselin, 2000), Internet surveys can provide important data for dealing with interactions between e-commerce and activity and travel behavior. Surveys of activity and travel behavior could be coordinated with ongoing Internet market research surveys, or travel behavior researchers can develop their own, aided by experiences gained elsewhere (Plaxton, *et al.,* 1999).

Choice-based samples require independent information regarding market shares in order to correctly estimate the standard errors of coefficients and to correct choice-specific constants for forecasting purposes. In Internet and other telecommunications-based surveys, this requires information about the penetration and use of the telecommunications technology (e.g., Internet connections) within a given territory. To date, most transportation planners have not sought to include any of these kinds of data in their inventory, and a recent discussion of future transportation data needs makes no mention at all of telecommunications data (Limoges, *et al*., 2000). If we are to make inroads into understanding telecommunication impacts on travel, these data will be needed.

6.3.3. Panel Surveys

Panel surveys are a superior way of collecting data to study this problem. Learning behavior, cohort effects, and exposure are of primary importance in the acquisition and use of information technologies. The obvious example is the age cohort effect on computer literacy. Dynamics are also potentially important in any activity behavior that can be influenced by IT. For instance, will workers who change working arrangements change their travel behavior in such a way that emulates the cross-sectional differences between workers in their former and present states, or will changes in travel patterns evolve differently, depending on history and cohort? We can only answer such a question with dynamic data. The travel behavior field has gained significant experience with panel surveys to justify their use without hesitation (see, e.g., Golob, *et al.,* 1997, Kitamura, 1990, Ma and Goulias, 1997).

We can gather valuable data using panel surveys to capture the effects caused by the introduction of new IT technology. Panels could be implemented to measure activity and travel behavior before and after the launch of a new communication device, such as a new type of handheld Internet device, or before and after the launch of new e-commerce opportunities. One such e-commerce opportunity is presented by the introduction of free at-work delivery of groceries by the Waitrose supermarket chain in central London. Participation in this service requires pre-enrolling employees in a company, which allows identification of program participants prior to initiation of the service. Of course, control samples are needed in all such before-and-after studies. It should be possible to persuade companies marketing IT products and services to provide samples and even financial support, in exchange for timely information concerning research results.

Time is of the essence. Studies of IT impacts on travel and activity behavior require quick-response data collection. If it takes two years to design, implement, code and check the data before they are ready for analyses, that is too long. Information technology is advancing too fast. With slow-maturing data of the type we are familiar with in travel behavior research, we will end up studying effects that are no longer relevant.

7. CONCLUSIONS

To date, very little relevant research has been conducted, and most of the research that has been conducted has focused only on one aspect related to IT: telecommuting. We must do better than that in order to keep our field relevant to planning and policy making. Travel behavior researchers ignore the impact of IT, particularly the impact of the Internet, at their peril. The effects of future IT on travel behavior is currently unknown, but we can be sure it will be substantial. This paper is meant to stir up discussion about ways to keep travel behavior research relevant in the information age.

Not since the introduction of the automobile age has transportation been faced with technological impacts of this scale. Telecommunications are just beginning to permeate almost every aspect of our lives. As we become busier, we will increasingly rely on IT to avoid unnecessary travel. As populations increase, particularly populations within metropolitan areas, we will also increasingly rely on IT to avoid congestion on transportation networks and at activity sites. Also, as we spend new time engaged in telecommunications, there will simply be less time available for other activities, including travel. Small effects by a very large number of persons will aggregate up to large effects on a system-wide basis

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