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Emerging travel patterns: Do telecommunications make a difference?

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ABSTRACT

This paper reviews empirical studies of the relationships between telecommunications and travel. The studies are classified into three approaches: macro-scale, micro-scale application-specific, and micro-scale comprehensive (activity-based). Within the second category we review the literature on the applications of telecommuting, teleconferencing, teleshopping, and the telephone. A diversity of relationships is identified, with some studies finding complementarity and others finding substitution. Hypotheses and directions for future research are discussed, including the need to further develop the comprehensive activity-based approach and to synthesize accounting exercises with behavioral modeling approaches to yield causal forecasts of the impacts of telecommunications on travel.

Emerging travel patterns: Do telecommunications make a difference?

1. INTRODUCTION

By definition, human interactions depend on communications among individuals and institutions. Such communications have taken place since the early days of civilization, through the use of two basic modes: traveling for the purpose of physical presence and various forms of remote interaction, from smoke signals to modern telematics.

Given that communications of both forms involve costs but convey different benefits, questions about the relative use of travel versus telecommunications[1] are warranted, and in fact ever since the invention of the telephone, more than a century ago, the issue of relationships between travel and telecommunications has been addressed (Pool, 1983).

Travel patterns are continuously changing. As most time series would clearly demonstrate, there is a universal increase in the reliance on the automobile, despite its social costs (Schafer and Victor, 1997); there is a widespread reduction in the use of public transport, even in most European cities, and people travel more, to more distant locations, at least during their holidays. Much has been written about the underlying causes for these developments: economic change which makes automobile purchase and use cheaper, social and demographic changes, particularly the changing role of women in society, changes in land use patterns and more. As some of the travel trends are considered to be socially inefficient, there is some interest in ways to mitigate excess travel. Technological changes, and the accompanying social changes, are suggested to offer such remedies. Do they make a dent in the overall current or future trends?

The recent growing interest in the relationships between transportation and telecommunications can be attributed to two separate trends. First, there is in recent decades a growing awareness of the full social costs of travel, as congestion and pollution are reaching high levels in some areas. Second, there is a rapid transition into what is often labeled 'the information age', in which information becomes a central asset in the economy, and information technology becomes a popular and inexpensive means for processing and distributing information resources. The intensity of these disparate trends has reached a level where information technology is now suggested to be a (partial) solution for the growing transport costs.

It is precisely that issue which this review paper intends to explore: Do telecommunications make a difference? The difference may be of relevance in two respects. First, does the growing availability of information technology, and the growth in the role of information in society, lead to

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[1] The term telecommunications is used here interchangeably with information technology (IT) and telematics. 'Telecommunications' refers to a broad set of technologies and services provided by such technologies. In the present context we choose to narrow the term to refer mainly to point-to-point interactive telecommunications networks. This excludes broadcast systems which are 'one-to-many' and commonly not interactive. The definition used here implies that the user must take action in order to engage in a communications session, much like the active action taken to engage in travel. Telematics are the systems and services which use telecommunications and computers to provide information and communications services.

changes in travel patterns that can be part of the solution for the infamous ills of transportation? This phrasing of the question seeks to establish a degree of substitution of telecommunications for travel. Second, whether or not substitution is a major phenomenon, what other types of changes in travel behavior can be expected?

To that end, we review the research of the last decade or so. The literature in the field seems to be mature to the point at which there are sufficient conceptual and empirical studies worthy of attention, thus avoiding the genre of previous scholarly work which included many descriptive and expository articles of a purely speculative nature.

Telecommunications and information technologies have penetrated many facets of human lives. Previously more limited to professional and employment situations, now such technologies are being used for a variety of domestic purposes, from household maintenance to leisure activities. People are exposed to IT in many different forms and contexts and consequently, their behavioral responses are affected by these multiple encounters with technology.

In the remainder of the introduction, we briefly discuss the notions of substitution and complementarity and also briefly review the types of studies found in this field.

1.1 A Typology of Relationships

A number of authors (ECMT, 1983; Mokhtarian, 1990; Niles, 1994; Salomon, 1985, 1986; USDOE, 1994) have described the different types of relationships between the two spatial technologies (transport and telecommunications) in various ways. We do not review that literature extensively here, but mention four main types of relationships: substitution (elimination, reduction), generation (stimulation, complementarity), modification, and neutrality. The first two are discussed at greater length below. By modification we mean, for example, that telecommunications may alter the time, mode, destination, route, or other characteristics of a trip which would have been made regardless.[2] By neutrality we mean, for example, that telecommunications has no impact on travel (as when the predominant effect of e-mail seems to be the generation of more e-mail; Balepur, 1997).

The interest in the telecommunications - transport interaction is twofold. Much attention in recent years is based on the underlying question of whether or not the two are substitutive entities[3]. If they exhibit such a relationship, then identifying its extent is of interest as an input to policy-making processes. This focus is paramount to policy makers, and to suppliers as well.

However, the behavioral research perspective is very different. Whether or not the relationship has immediate policy implications is of lesser importance. The implications of technology on behavior are of interest, regardless of whether they have a 'positive' policy potential. We should

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[2] Note however that while the number of person trips is by definition unchanged in this case, the number of vehicle trips, or the person- or vehicle-distance traveled, or the number of peak period trips, and so on, might change. Hence, the net impact of a particular modification effect might in fact be generation or substitution, in terms of one of those alternate indicators of the level of travel (e.g., an increase or decrease, respectively, in vehicle distance traveled).

[3] The term 'entity' is used to emphasize that both transportation and telecommunications are complex systems which entail technology, infrastructure and services.

attempt to understand the wide variety of factors which facilitate or restrict travel and activity patterns.

In this paper, we primarily focus on the two main types of interactions of interest: substitution 'versus' complementarity (or generation, or stimulation). We place 'versus' in quotes because, although the two concepts are contrasts, they are not mutually exclusive. The growth over the last century in the use of both telecommunications and travel, at almost any level of analysis, hints at a clear complementary relationship. On the other hand, the fact that modern telecommunications allow us such daily use of sophisticated, yet inexpensive communications, cannot, it is often argued, prevail without substitution of increasingly costly trips. Thus, it is the simultaneous presence of both types of impacts which makes the study of this issue so challenging.

Whereas substitution seems to be a more straightforward relationship, where the main question is the extent to which it is occurring, complementarity seems to be a more complex relationship, by nature.

For two entities to be substitutive they need to offer very similar functions with very similar properties. A user will be indifferent if two entities provide essentially the same utility at similar costs and the indifference is interpreted to imply perfect substitution. Indifference is an extreme point in the distribution of preference. Slight differences in the quality of products will result in a removal from indifference to preference of one over the other. Substitution may result from the fact that one option is more attractive, and/or because it provides similar utility but has lower costs. As individuals differ in their preferences for particular attributes, substitution too may take place for some people and some of the time. Technological substitution, such as that observed for the transition from wood or metal to fiberglass boats or from turbo-prop to jet engines are often cited as examples (Linstone and Sahal, 1976) of situations where one option dominates the other on all or at least the important determinants of preference. However, in many cases there is no clear dominance. So, the question of substitution between travel and telecommunications must examine the extent to which travel and telecommunication are indeed similar.

Complementarity, on the other hand, depends on the degree to which each technology or service elicits the use of the other. The range of possible relationships here is wide. Perfect complementarity exists when one product cannot be used without the other. This is clearly the case for face-to-face communications, which cannot be accomplished without travel. However, complementarity also relates to situations in which the use of one product encourages the use of the other, although not necessarily a simultaneous use. Experience with the telephone over the last century exemplifies this relationship, in which telephone-based communication has grown in parallel with, and not totally independent of, the growth in travel-based communication. Both of these types of complementary relationships may be considered examples of *enhancement*, in which the use of one mode of communication directly increases the use of another mode.

Another type of complementary relationship deals with situations where one product makes the use of another more *efficient*. Efficiency gains in the use of either travel-based communications or telematic-based communications, attributed to the use of the other, are probably prevalent. Real time or short term coordination of meetings by use of mobile communications serves as an example of one direction. In the other direction, improved communications (and fewer errors) in

telematics-based communications may be attributed to personal acquaintance based on face-to-face communications between the parties involved in a communication process.

1.2 A Typology of Studies

Dozens of articles and books addressing, directly or indirectly, the topic at hand have been published in the last fifteen years. The studies of this subject vary in so many dimensions that a formal classification is beyond the scope of our present task (see for example, Salomon, 1986; Salomon, forthcoming). Briefly, however, some major classes should be described.

One important reason for classifying the literature in the field is to distinguish between studies which are based upon some theory or scientific approach and those which are closer to science fiction or commentaries. Writings about the impacts of technology commonly include both types, and much of the widespread expectations with regard to technological fixes emanate from the latter. A classification at this point of time is important, among other reasons, in order to avoid the indiscriminate citation of studies which often lead to premature conclusions.

Much of the literature in the field is based on 'armchair' exercises in which ideas regarding possible relationships are exposed for further study. These are usually expectations which draw on the experience with other technologies and on the interpretation and professional judgment of the authors based on available knowledge in relevant fields. At the opposite end of the spectrum from the armchair research lie the empirical studies which undertake the testing of specific hypotheses on the basis of revealed behavior. All studies, in fact, fall somewhere on a continuum between the armchair and empirical approaches.

Another criterion for classification is the time horizon addressed in the studies. Some studies focus on the short-term while others deal with long-term perspectives. There are two important differences between these types. First, long-term analyses entail much greater uncertainty with regard to technological advances. This is a serious restriction in an era characterized by rapid dynamics. Second, and even more difficult to address, long-term studies face more uncertainty regarding changes in societal values and norms. Social scientists who address such issues may be at risk of dealing with science fiction. Short-term studies can avoid this pitfall, but consequently, may be poor predictors.

Studies also differ in the range of relationships they address. Most focus on the *direct* impacts, namely the extent to which the use of one technology directly affects the relative use of the other. Fewer studies (e.g., Lund and Mokhtarian, 1994; Salomon, 1996) also address *indirect* impacts like the effects of telecommunications on land use, and through such changes, on travel behavior.[4]

Yet another distinction can be made between studies, in terms of the breadth of the question addressed. Some studies are comprehensive, trying to unveil the relationship between transportation and telecommunications in a broad context. In this category, for example, a focus on substitution of a single trip type (e.g., work or shopping) would be 'unjustified', as it is possible that

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[4] Numerous researchers (e.g. Brotchie, *et al.*, 1985; Gottman, 1983; Graham and Marvin, 1996; Mandeville, 1983; Nijkamp and Salomon, 1989; OECD, 1992) have examined the impacts of telecommunications on land use. The focus here is on the subsequent effects of those land use changes on travel, which are seldom addressed with any specificity.

changes in travel with respect to one trip type will change not only the entire communication and trip-making patterns of the individual, but also the activity patterns of other household members. Comprehensive studies explicitly recognize the interrelationships among the various modes (and submodes) of communication - face-to-face (involving passenger travel), exchange of a physical object (involving goods movement), and telecommunications (Mokhtarian, 1990) - and focus on the combined, systemwide effects of such relationships. Other studies are limited to the analysis of particular situations, with implied or explicit recognition (or ignorance) of the broader context within which the limited case is relevant.

Finally, the distinction can be made between macro-scale (aggregated to regional, national, or international levels) and micro-scale (disaggregate, individual-level) approaches. For the present context we categorize the empirical studies reviewed into three research approaches, shown in Table 1, which shows a cross classification of Limited vs. Comprehensive studies and Macro-scale vs. Micro-scale studies. This results in three research approaches, discussed in the subsequent sections of the paper. One cell of Table 1 is empty, since there are, to the authors' knowledge, no *empirical* studies that examine a limited scope on a macro scale (there are several such studies of a *hypothetical* nature in the areas of telecommuting and teleconferencing, e.g. USDOT, 1993; USDOE, 1994; Harkness, 1977).

Table 1: A Classification of Research Approaches

		Scope of Coverage	
		Limited	Comprehensive
Scale	Macro	(not used)	Industrial and consumer contexts
	Micro	Application-specific	Activity analysis

To maintain a manageable scope for this paper, we have limited our review specifically to studies which have either provided a theoretical or conceptual framework *for the relationships between telecommunications and travel*, developed testable hypotheses on those relationships, or in fact tested such hypotheses in an empirical or quasi-empirical context. We do not extensively review studies which confine themselves to modeling the adoption of telecommunications-related activities (such as telecommuting or teleshopping), although we discuss the role of such studies in Section 5.

The analogy between the evolution of the research in this area and in travel behavior is illustrative. Early work focused on aggregate studies and evolved into disaggregate, micro-level analyses. Initially, behavioral models focused on specific choice situations (e.g., mode choice, destination and so on), and later the focus shifted to activity-based approaches. In studying the relationship with telecommunications, it seems that we have now reached the point in which we need to progress from specific applications to activity-based approaches. We will return to this in the concluding section.

Sections 2, 3, and 4 address, in turn, each of the three research approaches shown in Table 1. In each case, we provide a brief description of the approach, summarize any empirical results to date, and assess the advantages and disadvantages of the approach. Section 5 examines the importance of behavioral modeling of activity mode selection to understanding the relationship between telecommunications and travel. Section 6 discusses the implications of the literature reviewed here and suggests directions for further research.

2. THE MACRO-SCALE COMPREHENSIVE APPROACH

Description of approach: The macro-scale comprehensive approach to studying telecommunications – transportation relationships analyzes transportation and communication sectors of the economy in the aggregate to determine the net impact of each sector on the other(s). To date, the macro-scale analyses undertaken have focused on the national and international scales, but the same methods could be applied to state, regional, or even metropolitan economies if those were of particular interest and if the appropriate data were available at those levels.

To the authors' knowledge, only three studies using the macro-scale approach have been published, and they are complementary both in methodology and in results. Selvanathan and Selvanathan (1994) used the Rotterdam demand system, a set of equations simultaneously modeling the demand for multiple commodities, to analyze relationships in *consumer demand* for the private transportation, public transportation, and communication sectors of the economy. They compared the United Kingdom and Australia, using time-series data for the period 1960-1986. The Netherlands Organization for Applied Scientific Research (1989, cited in Button and Maggi, 1994) has taken a similar approach. Plaut (1997), on the other hand, argues that industrial uses account for half to two-thirds of all expenditures on transportation and communication in the U.S. and Europe. Accordingly, she used cross-sectional input/output analysis to analyze *industrial demand* for transportation and communication in nine member countries of the European Union in 1985.

Results: The results of the studies are intriguing. Selvanathan and Selvanathan found that, at the consumer level, private transportation, public transportation, and communication were pair-wise *substitutes*, but with relatively small price elasticities (e.g., in the UK, the price elasticity of communication with respect to private transport was 0.57). They further found exponential growth in communication, at the expense of the two types of transportation. Similar results have also been put forward by NOASR (1989), suggesting relatively low elasticities and a reduction of travel by only 8% over the next 35 years.

Plaut, by contrast, found that at the industrial level, transportation and communications were *complements*. Both results are plausible, although replication studies are essential.[5] The consumer-oriented finding of net substitution is consistent with the nearly unanimous empirical results of numerous micro-scale studies (presented in Section 3 below), whereas the industrial-oriented

[5] It would be of particular interest to apply the time-series approach to industrial data and the cross-sectional approach to consumer data (or better yet, both approaches to both kinds of data), since the use of those two different approaches may be a confounding factor in the difference between the two outcomes.

finding of complementarity is consistent with historically-observed simultaneous increases in both transportation and communication in the aggregate (see, e.g., Niles, 1994).

The divergent findings are not only empirically substantiated, but are also conceptually reasonable (Plaut, 1997). As indicated in the Introduction, complementarity can arise both through an enhancement effect (in which use of one mode of communication directly stimulates use of other modes) and through an efficiency effect (in which use of one mode in conjunction with another improves the efficiency of the latter). It is quite possible that both effects are obtained more strongly in an industrial context than in a consumer one. For example, the expansion of personal contacts through electronic means is more likely to lead to increased travel (enhancement) in a business context than in a social one. The use of electronic data interchange and global positioning systems (efficiency) have benefited goods movement more than, say, automobile drivers. On the other hand, intelligent transportation systems (ITS) approaches may begin to shift that balance as efficiency-improving technologies such as in-vehicle navigation systems permeate the consumer sector more deeply. Hence, it is possible that, over time, the net substitution effect now seen for consumer demand may weaken and even reverse into a complementary effect. This again calls quite urgently for studies replicating the Selvanathan and Selvanathan methodology at other times and places. The latest year in their time-series data was 1986; a shift may already be detectable in the intervening decade.

Advantages and disadvantages: The macro-scale comprehensive approach has the obvious advantage of offering a 'big picture' view. It illuminates the net sectoral impacts of telecommunications and transportation in a way that neither of the micro-scale approaches described below can possibly do. It offers the potential for developing aggregate forecasts of the impacts of telecommunications on travel (and conversely) more readily than the other two approaches. On the other hand, the macro-scale approach does not completely dominate the others in conceptual superiority and usefulness. The macro-scale approach offers no insight into behavioral or other causal mechanisms driving the observed results. Its findings are based on the temporal or cross-sectional relationships exhibited by the data analyzed, but the focus on net impacts may conceal various counteracting relationships. If the underlying structure of those relationships changes over time or space - as, for example, may be the case for the impact of ITS and other telecommunications technologies on consumer demand for communication and travel - then its findings will not be robust.

Further, the focus of this approach on economic value (measured in dollars or other units of currency) may obscure some relationships. In some contexts (for example, understanding the impacts of telecommunications on urban traffic congestion), *volume* is more important than *value*. The number of person-trips made, and the number and length of messages flowing over an electronic link, are of legitimate interest in assessing the impacts of one mode of communication on another. The relationship between value and volume will probably differ by mode and over time: in brief, one might expect that, over time, volume of activity per unit of monetary value has been rising more rapidly for telecommunications modes than for transportation (Webber, 1991). If that is true, then a finding that, say, expenditures on communication and travel are positively correlated may or may not mean that volumes are rising together as well, and conversely.

3. THE APPLICATION-SPECIFIC APPROACH

Description of approach: The application-specific approach analyzes one telecommunications application at a time. It is by far the approach most often taken in empirically assessing the impacts of telecommunications on travel. The evaluation is generally performed by collecting survey data from individual users about the transportation impacts of the application. The survey may be prospective (e.g., stated preference), contemporaneous (e.g., travel diaries), or retrospective.

Advantages and disadvantages: The application-specific approach has the advantage of manageability. It offers the opportunity for a detailed look at the impacts of a single type of communication, for which the boundaries around the activities or process being studied can be relatively easily drawn. Studying individual behavior brings the analyst closer to the decision-making unit than is the case for the macro-scale approach. On the other hand, this approach has clear disadvantages as well. By narrowing the focus to a single application context, it is easy to lose sight of the big picture. The short-term nature of most studies in this category may give rise to findings that will change considerably over the long term. In particular, this approach seems likely to underestimate any stimulation effects of telecommunications, which tend to be longer-term and more indirect (occurring outside the boundaries of the process being studied), in favor of the shorter-term and more direct substitution effects.

Results: As noted above, the key question in studying the degree of potential substitution between competing technologies or services is the extent to which they fulfill similar needs, at similar costs. Three activities and their telematics-based alternatives are discussed below: work, conferencing and shopping. We would argue, for each one of them, that the telematics-based alternative is a substantively different activity or experience and consequently, the degree of substitution depends not only on how well the tele-activity fulfills the 'basic' function (work, convey information, or shop), but also on the distribution of preference with regard to the other aspects of the activity.

It is also necessary to recall that advanced telecommunications are not supplied in a vacuum, in which individuals (and more so, policy makers) are acting to reduce travel to work, conferences, and shopping. The other parties involved in these industries may have a different agenda, acting quite vigorously to encourage visitation to shopping malls and to convention centers, and airline travel. Thus, tele-activities may offer new opportunities, but their relative attractiveness also depends on changes in a very dynamic environment (Albertson, 1977).

In the sections below, we discuss key results relating to the applications of telecommuting, teleconferencing, and teleshopping. We also review recent studies of the impact of the telephone (conventional and cellular) on travel.

3.1 Telecommuting

Commuting constitutes the single largest trip purpose, in terms of its share both of trips and of distance traveled (Hu and Young, 1992; US DOT, 1997). Further, it is the most routine type of trip, performed in very well-defined time slots and serving as an anchor to which other trips are chained. It is therefore the trip purpose contributing most heavily to peak-period congestion in urbanized areas. Further, it seems likely that a higher number of commute trips would be

amenable to substitution by telecommunications than would be the case for other trip purposes such as shopping. For these reasons, the potential of telecommuting for reducing congestion holds particular appeal for policy makers and planners, and hence telecommuting is doubtless the most commonly-researched telecommunications application in the context of understanding its travel impacts.

Technically speaking, work entails the performance of particular tasks, usually at defined times, in return for some (financial) compensation. However, it is clear that the quality of this activity extends widely beyond the time, task and compensation. Under this view, the performance of many work situations can easily be carried out through telecommunications. But, for many people, work is a series of tasks that require face-to-face communications, it is an opportunity to socially interact with others, it serves as an opportunity to exit the home environment for some time, it is an opportunity to see and be seen by others, and so on. In a nutshell, work often involves, in addition to the financial gains, social and psychological gratification that may not be recognized or explicitly stated, even by the individual.

Although net substitution is obviously the most (socially) desired and perhaps the most expected effect of telecommuting, it does not mean that the same holds true for the individual. To the extent that other employment-related benefits and costs are important to the individual, the likelihood of substitution will be affected.

Furthermore, travel stimulation is certainly possible as well, due to non-commute trip generation, changes in mode choice from ridesharing or transit to driving alone on regular commuting days, induced demand caused by the same telecommunications technology which supports telecommuting, latent demand[6] realized if telecommuting perceptibly reduced congestion, and long-term changes in residential location which increase commute lengths (Salomon, 1985; Mokhtarian, 1991, 1998).

Numerous individual studies of telecommuting have been conducted (Hamer *et al.*, 1991, 1992; Henderson *et al.*, 1996; Henderson and Mokhtarian, 1996; Kitamura *et al.*, 1990; Koenig *et al.*, 1996; Pendyala *et al.*, 1991; RTA, 1995; Varma, 1997), and reviews of empirical results have periodically appeared (Mokhtarian, 1991, 1997, 1998; Mokhtarian *et al.*, 1995; Nilles, 1988). The studies generally involve the collection of multi-day travel diary data before and some months after telecommuting began, often from a control group of non-telecommuters as well. These data are then analyzed to ascertain the impact of telecommuting on travel indicators such as number of trips and distance traveled. To date, there is some empirical evidence on non-commute trip and mode choice impacts, little evidence on residential relocation impacts, and virtually none on induced and latent demand impacts.

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[6] Although the terms 'induced demand' and 'latent demand' are often used interchangeably, we distinguish them. By *induced demand* we mean travel generated directly by telecommunications, such as finding out about an activity through a community network and then traveling to that activity. By *latent demand* we mean the phenomenon that increasing the transportation system capacity, or reducing the costs (whether through providing new infrastructure or, in this context, through telecommunications reducing demand), attracts new vehicle trips, whether through changes of mode or route, new development along the corridor, and so on. Neither necessarily implies the other: even though the capacity may be freed up through tele-substitution, the latent demand could be realized by anyone for any reason. And induced demand can be generated by telecommunications even if no travel were substituted (and hence no capacity were freed to attract latent demand).

All the empirical studies are unanimous in finding that total distance traveled by telecommuters decreased markedly on telecommuting days. The change in non-commute trips and distance was sometimes positive and sometimes negative, but essentially statistically negligible. Interestingly, studies of telecommuting centers found a small *increase* in *commute* trips on telecommuting days, mostly due to trips home for lunch and back to the center in the afternoon, but again, the net reduction in distance traveled remained substantial. Little actual shift in mode choice has been found, although there was some evidence that trips eliminated by telecommuting tended to be disproportionately by transit or rideshare modes. That is, the more difficult-to-use modes were the ones more readily given up. No significant impact on residential relocation has been measured to date.

Hence, the empirical results so far indicate a net impact of substitution. Given the unknown extent of the induced demand, latent demand, and long-term residential relocation effects, however (as well as the likely unrepresentativeness of the early adopters of telecommuting analyzed in these studies), it is certain that the long-term, systemwide effects of telecommuting will be less positive than is suggested by the results from the short-term, small-scale studies conducted to date. It is not certain *how much* less positive, but it is possible for the generation effects to nearly equal or even exceed the substitution effects. Two studies of the latent demand issue, one in the context of telecommuting (USDOE, 1994) and the other in a general context (Hansen and Huang, 1997) suggest that the realization of latent demand could amount to anywhere from 30 to 90% of the newly available capacity. Some initial evidence on the induced demand issue is offered below in Section 3.4.

3.2 Teleconferencing

Teleconferencing, increasingly in the form of videoconferencing, enables individuals or groups to conduct information transfers while being spatially separated. The information typically is verbal (with visual cues in the case of videoconferencing), often supplemented by written or graphical material. Teleconferencing systems vary in sophistication and costs, as well as in accessibility (some require specialized studios, thus imposing greater need for pre-conference coordination, while others are readily accessible). Generally, the market for teleconferencing is in the institutional (private and public) sector and not in the domestic sector, although simple desktop videoconferencing systems being developed for personal computer users may eventually find a niche there too. Button and Maggi (1994) have looked into adoption patterns in Switzerland and the United Kingdom and found that large, often multi-national corporations are likely to be early adopters, primarily for intra-organizational communications. This is consistent with product life cycle theory.

The ability of teleconferencing to reduce travel is a very popular notion in the promotion of these services as well as in the popular literature (e.g., Arvai, 1994). In many cases, promotion material is very explicit about the trade-off and the expected cost savings due to the eliminated travel. However, some providers seem to agree that the substitution effect is only used for promotion to budget-conscious decision makers, whereas for the most part, the benefits of videoconferencing are simply the increase in inter-organizational communications, and not the trip savings (see, e.g., Egido, 1990; Mette, 1995). Further, as Salomon *et al.* (1991) point out, even straightforward cost considerations do not always favor teleconferencing. They illustrate that, under then-prevailing price structures, travel costs could be lower than telecommunications costs for meetings involving short distances, long duration, and/or few participants. While the costs of

teleconferencing have fallen since that study was conducted, there are likely still to be instances in which the trip can be justified in purely economic terms.

Applications of the technology include four basic types of 'electronic meetings': formal group meetings, informal group discussions, single presentations and repetitive presentations. Each seems to have different travel implications. For all types, the technology is increasingly user-friendly, costs are falling, and availability is increasing.

Formal group meetings are electronic conferences, intra- or inter-organizational, in which people convene without the need to travel for face-to-face meetings (although some short travel may be necessary to a studio). Periodic conferences incur high costs on organizations which have to pay the travel and accommodation costs, in addition to the costs of time. Thus, using videoconferencing as a cost reduction strategy seems attractive. But organizations, and individuals within them, have recognized that travel to conferences entails external benefits (Button and Maggi, 1994). These include the value of face-to-face interaction in terms of the richness of information exchanged and opportunities for personal acquaintances (which may improve future mediated communications), as well as perks such as the break in routine and the enjoyment of visiting appealing places. All these aspects are eliminated from videoconferences, and in this respect the two types of meetings are far from being similar. Consequently, they are also less amenable to substitution. Again, the importance of such attributes is not uniformly distributed among employees, and it is reasonable to assume, for example, that those who travel much assign lower values to these attributes at the margin, compared to those who travel least.

Informal meetings usually take place among team members within or across organizations[7]. These are more routine meetings involving people who usually know each other and share an organizational culture. These meetings may be substituting some travel between facilities of an organization, but in many cases they do not, as the users may all be in the same facility, with little or no physical separation. Arguably, this category has the most potential for substitution. But even here, new uses of the videoconferencing facility are likely to arise which do not replace regularly-scheduled in-person meetings, but rather which represent communication that would not have occurred otherwise.

Single presentations of new products seems to be one of the most popular applications of videoconferencing. This is to a great extent similar to broadcast systems where a new product or service is announced and potential clients gather in locations across the country or the world and can view the announcement and present (usually audio-only) questions to the originating agent. This is increasingly also used for religious activities. We hypothesize that this form of teleconferencing does not replace travel (in fact it probably generates local travel to the videoconference location) and that it is more of a marketing tool. In its absence, some alternative, possibly a travel-based mode of promotion, would be used but it is highly unlikely that significant differences in travel would take place.

Repetitive presentations relate especially to education and training applications of teleconferencing. Here the technology is used to distribute information to students who may be spatially scattered in remote classrooms or even in their homes. Of course tele-education differs in many

[7] The distinction between inter- and intra-organizational communications is important but sometimes blurry. Some very big organizations, like NASA or IBM, which operate in multiple locations, can have systems which are officially intra-organizational but in effect may be used inter-organizationally.

respects from the traditional classroom environment. It is widely applied in contexts where either the students or the teachers experience a mobility constraint (permanent due to distances, such as in Australia and Canada, or temporary, due to illness). Although the technology facilitates engagement in activities which formerly were inaccessible, it may not always result in substitution, that is, in being used in lieu of travel.

A common theme for all four of these types of electronic meetings is that not every teleconference substitutes for a trip to the in-person version of the same meeting (Albertson, 1977). In many cases, the alternative to 'teleconferencing' is not 'traveling to the meeting', but rather 'not attending the meeting at all'. Hence, the primary impact in those cases is the generation of new communication, not the replacement of travel. Even when travel is substituted, as, say, in the case of routine informal meetings, the time thereby saved may be partially spent in making non-routine trips which are not readily replaced by telecommunications, such as those to the desirable conference locations, or those involving establishing a new business relationship.

Most of the literature dealing with teleconferencing (e.g. Egido, 1990; Johansen and Bullen, 1984; Green and Hansell, 1984) focuses on the quality of the communications process, in all of the above types. Much attention is paid to the applications for educational purposes. Given a lack of data due to the novelty of the technology and the fact that many organizations do not maintain sufficiently detailed data on teleconferencing and travel (Button and Maggi, 1994), very few studies have empirically addressed the impacts of teleconferencing on travel.

Bennison (1988) analyzed the effectiveness of videoconferencing for a UK trial in the early 1980s. Among other findings, 87% of the 31 users responding to that part of the study reported a decrease in travel (and a smaller decrease in other modes of telecommunications) due to videoconferencing. However, there are a number of concerns with such a number, aside from the small sample on which it is based. Respondents are reporting a general perception, not a careful measurement of actual travel before and after the trial began. They may be more aware of the direct effect on trips eliminated (especially if those were the less pleasant, more routine trips), than of indirect effects involving 'in-fill' travel. The promotion around the trial may have sensitized them to an expected outcome of travel savings, thereby biasing their responses. And finally, they may be reporting a short-term outcome before new stable patterns of travel are achieved. The author of the study, examining all the evidence, concludes that "...clearly substitution of the former [face-to-face meetings] by the latter [videoconferences] was at best partial. Indeed, the pattern that emerged was essentially that of videoconferences complementing conventional meetings rather than supplanting them" (Bennison, 1988, p. 293).

Mokhtarian (1988) studied an experiment in which a regular monthly meeting of the Southern California Association of Governments was held by videoconferencing instead of conventionally. While participating individuals reduced their trip length to the meeting on a per capita basis (by 24% on average), thus indicating substitution, more participants took part in the meeting, increasing total distance travelled (by 29%) and thus indicating a complementary relationship.

Erdal and Hallingby (1992) studied the impact of the 1991 Persian Gulf war on travel and telecommunications to and from Norway. They found that while air travel declined noticeably due to the fear of terrorism (at least 40,000 fewer passengers in each of the three months January - March 1991, compared to the same period in 1990), the increase in telecommunications (teleconferencing as well as ordinary voice and data traffic) was negligible by comparison. This

occurred despite considerable media attention being devoted to the use of telecommunications as a substitute. In fact, the primary impact on travel seemed to be the postponement or cancellation of planned trips rather than fulfillment of the same purpose through telecommunications.

Our understanding of teleconferencing allows us to speculate about its future impacts on travel. It is not likely that the demand for business travel will be reduced to a noticeable extent. The other contributing motivations for travel (the external benefits) will simply carry more weight. However, organizations (which develop travel-telecommunications policies) will be able to sustain some reductions in travel when conditions require them to do so, while still maintaining contact with their counterparts. Thus for teleconferencing (and other telecommunications used in the business sector), complementarity is probably the dominant effect, with the potential of some limited substitution.

3.3 Teleshopping

Shopping refers to a service (or activity) which takes a variety of forms, but common to all is the ability to obtain information about products and services and to perform a transaction by which ownership is transferred and a product or service is spatially relocated to its new owner.

The 'shopping revolution' (Batty, 1997) offers a growing range of ways to do it. The conventional store environment has now diversified itself from street corner stores, to neighborhood supermarkets or specialty stores, to shopping centers and shopping malls, to factory outlets, warehouse stores or clubs and variants thereof. Likewise, non-store shopping can be done by catalog in combination with a telephone, fax or mail. The newcomer is the computer-based *teleshopping* which essentially can be seen as the combination of real time catalog information and transaction modes. There is much variation in the forms of teleshopping and that variation is likely to increase. Many references to teleshopping suffer from the blurry use of terms, referring, for example, to TV-based home shopping as teleshopping. Consistent with the above definition, we focus here only on active shopping, namely an activity for which the individual engages in a search for a product and may in fact generate a purchase.

Understanding whether or not teleshopping replaces conventional shopping activities requires an analysis of the nature of shopping activities, and through that, an examination of the extent to which teleshopping modes offer substitutable activities.

As in other choice situations, the decision on whether to use one of the many travel-based shopping modes or to use a home-based mode, depends on the extent to which these activities are in fact similar enough to be substitutes, and on the characteristics of the decision-maker.

Store shopping is presently (still) very different from teleshopping in terms of such attributes as the information provided, the sensual stimulation, the ability to compare prices and to attain immediate ownership. Beyond the functional attributes related to shopping and purchasing, store shopping also offers numerous other experiences which at present (and probably in the future) are not amenable to electronic environments. These include, for example, the ability to interact with salespeople and to bargain, the opportunity to be outside the home or work environment, and so on. Shopping, for many but not all, is a combined maintenance - leisure activity. Shopping modes differ in numerous attributes, thus entertaining different tastes, time and money budgets, and 'activity integration'. This term refers to the degree to which each shopping option allows or

facilitates other activities to be intertwined with the shopping activity. For example, shopping at a mall offers high activity integration, as opposed to shopping at a street-corner grocery.

One can (and should) assume that teleshopping services will be increasingly user-friendly, especially with respect to the quantity and quality of product information supplied to users. With the increasing similarity to the 'real' shopping experience, it is plausible to assume that more substitution will take place.

But, the choice of shopping mode also depends on the individual's preferences and attitudes (Handy and Yantis, 1996). Individuals who prefer out-of home activities, especially if they are confined to home due to work (e.g. telecommuters) or household responsibilities, are likely not to forego the store shopping opportunities. Conversely, individuals who have a very busy schedule and desire some quiet time when off work, may prefer to use home-based shopping options, as reported by Gould *et al.* (1997).

While shopping alternatives are changing in character and becoming more diverse, one could assume that human attitudes toward in-home and out-of-home activities do not change at the same pace. We would speculate that basic attitudes toward the two types of activities change rather slowly. Thus, segmentation of the market on the basis of attitudes and preferences will provide some understanding as to the relative potential of substitution.

Koppelman *et al.* (1991), using hypothetical choice models, have shown that teleshopping is probably perceived as an electronic catalog, and at least in the context of shopping for appliances, does not seem to be substitutive to store shopping for those who would not purchase from a catalog. On the other hand, Balepur (1997) reports anecdotal evidence that computer-based information acquisition regarding an automobile purchase saved the respondent trips to multiple dealerships for the same purpose, and that another respondent reported saving trips to computer stores by finding and downloading a desired piece of software online.

Handy and Yantis (1996) point to the complexity of the relationship, suggesting that some substitution may occur as systems develop, but again supporting the case that store shopping is a different adventure, thus not easily substitutable. Gould *et al.* (1997), using structural equations to estimate time allocation between activities, point to the fact that busy women are more likely than others to take advantage of home-based shopping modes. Tacken (1990) found that users of a grocery teleshopping service in the Netherlands were predominantly (a) older people who chose it because of their limited mobility, and (b) dual-income households who chose it to save time.

As the development and adoption of teleshopping modes are still in their infancy, the authors are not aware of any empirical studies explicitly examining the impact of teleshopping on travel patterns. From a systemwide perspective, as opposed to the individual's behavior, any potential substitution of shopping trips by home-based shopping must account for the generation of delivery trips. The VMT produced by these must be subtracted from the saved VMT attributed to teleshopping substitution. The net effect is not clear. Delivery could, in principle, be organized into efficient trips, but at the expense of quality of service. The demand for fast delivery, for example, is clearly inconsistent with efficiency. Furthermore, shopping trips are often chained to other trips. To the extent that those other trips still occur when the shopping trip is eliminated, the calculated VMT reduction must be adjusted accordingly (Handy and Yantis, 1996).

The bottom line, it is suggested, is that teleshopping is not likely to have a noticeable effect on travel reduction or enhancement, as processes cancel each other and there is no overriding effect that clearly dominates.

3.4 Conventional and mobile phones

The telephone is clearly the most accessible form of telecommunications, with penetration levels exceeding 90% of the households and most business establishments in western countries. As noted earlier, interest in its impact on travel dates back to its invention. The demand for telephones can be separated into the demand for access and the demand for use. In a series of studies on the telephone's impacts during the first half of the century, Fischer (1987) and Fischer and Carrol (1988) show that in the choice between a car and a telephone, many American households during the Depression preferred the former, which had a greater perceived promise for economic productivity.

In recent years the plain old telephone has assumed numerous innovative uses. Aside from a series of smart services such as call waiting, call forwarding, and caller identification, telephone lines are now commonly performing facsimile and data transmission services in businesses and in homes. All these make the telephone an elaborate telecommunications medium, which potentially increases the options for substituting travel-based activities. Probably the most significant innovation in telephony in recent years which has direct ramifications for spatial behavior is the introduction of relatively cheap and accessible *mobile* telephones.

Nevertheless, relatively few studies have empirically examined the impacts of the telephone itself on mobility. One key study was reported by Claisse and Rowe (1993), who surveyed the residential telephone use of 663 people living in the Lyon, France metropolitan area in 1984, using a one-week diary of all calls made and received while at home. Among other questions, respondents were asked whether each call led to an unplanned trip (generated travel), and what they would have done if the telephone network had been down for an extended period (to which responses of 'made a trip' or 'sent someone' imply that the phone call replaced a trip). Depending on their focus (local calls only or all calls), Claisse and Rowe estimated that residential phone use generated trips 3-5% of the time, and replaced trips 21-27% of the time, for a net substitution impact of 17-22%.

On the other hand, Massot (1997) compared those who used the telephone (most often a pay or stationary phone) *during trips* (4.6%) to those who did not, for a sample of 14,000 French respondents to a 1994 national survey of travel and communications behavior. She found evidence of (efficiency-related) complementarity in that those who used a phone during trips were considerably more mobile (longer trips, greater travel time) than those who did not. She concluded that "there is much more complementarity than substitution between modes" [telephone and travel], and that the telephone plays an important role in the management of the lives of busy people.

Finally, Yim (1994) studied the role of the cellular telephone in daily travel, through a 1991 mail survey of 7,347 cell phone subscribers in the San Francisco Bay Area. Regarding the present context, the general conclusion is drawn that 'the effect of the cellular calls on trip reduction was more significant than trip generation.' For example, 14.8% of the respondents reported driving less often after getting a cell phone than before, compared to 8.0% reporting driving more often.

Similarly, 11.5% reported driving shorter distances afterwards, compared to 5.8% driving longer distances.

However, these results should be interpreted with caution. As with the teleconferencing results mentioned in Section 3.2, these numbers represent the respondents' general impression, not a rigorous measurement. Further, the proper attribution of causality is not clear. The question was phrased in terms of, 'after getting a cell phone', but that is not necessarily 'because of the cell phone'. Conversely, when the respondents reported making an unscheduled trip 'because of' a cell phone call, they may actually have just meant, 'using' a cell phone. If, without the cell phone, a pay phone would have been used, or the call would have taken place at another time, then it was not the cell phone *per se* but rather any phone that caused the trip.

None of these results permit a mile-for-mile calculation of net impacts. In the Claisse and Rowe study, for example, it is not known whether the generated trips are longer or shorter on average than the replaced trips. Similarly, in Yim's study, without knowing how much shorter or longer the distances were after obtaining the cell phone compared to before, the net impact on VMT cannot be computed. Even the impact on number of trips cannot be measured, since the increase in trip-making for those who reported driving more often might exceed the decrease for those reporting driving less often.

4. THE ACTIVITY-BASED APPROACH

Description of approach: The activity-based approach is the newest of the analysis methods presented here. To date, empirical applications are only partial at best. But the approach seems to have been spontaneously and independently generated among several researchers, as a logical next stage in our analysis capabilities. Conceptually, the activity-based approach falls between the other two approaches discussed. The activity-based approach is micro-scale, with measurement taken at the disaggregate level, but in theory it takes a comprehensive look at an individual's communications activity rather than focusing on a single application. As Claisse and Rowe (1993, p. 277) indicate, a key reason for the neglect of the stimulation effect (both of new travel and of new telecommunications that would not have occurred anyway) is that "this work is often based on an in-depth analysis of the demand for transport; few studies start off from an analysis of the demand for and the use of telecommunications in order to evaluate their influence on transport." The activity-based approach is intended to remedy this deficiency precisely by making the holistic study of communications the focus, rather than the demand for transportation in a specific context.

The methodology is expected to involve a specialized activity or time use diary, through which measures of the amount of engagement in *each* mode of communication, over some period of time, can be obtained. Those measures should permit the analysis, perhaps through the use of techniques such as (time-dependent) structural equations modeling, of the impacts of each communication medium on itself and the others over time. Socioeconomic and other explanatory variables can be controlled for in such an analysis.

Results: As indicated, this approach has not yet been applied in its entirety. Work is in progress at the University of Texas, Austin on a project with a similar approach. Zumkeller (1996) describes a study in which 166 employees of the University of Karlsruhe, Germany completed diaries recording information on all trips and contacts (communication activities) they made for one

day in 1994. He concludes (p. 79) that "the complementary factor of the interrelationship between travel and communication is much stronger than the substitutional one" since high levels of trip-making were found to be associated with high levels of communication activity.

Recently-completed and additional work in-progress at the University of California, Davis also represents an early attempt to partially implement the activity-based approach. The study involves evaluating the communication and travel impacts of the Davis Community Network (DCN). DCN was launched slowly, beginning in January 1994; it is still in operation today. At the time collection of the evaluation data was completed in June 1995, the primary features of the system were electronic mail, newsgroup-reading, and web-browsing capabilities. In view of that, the evaluation constitutes primarily an assessment of the impact of Internet access on communication and transportation. That impact, especially on transportation, may not be expected to be sizable – particularly not as sizable as might be expected if more information about community activities had been posted and if more transaction opportunities had been available at the time the evaluation data were collected. Notwithstanding that, the methodology used in the study is of broader applicability, and even the empirical findings themselves are of some intrinsic interest.

Multiple data collection instruments were developed for the evaluation. In the present context, two instruments are most relevant: an Activity Diary, collecting data on the antecedents and likely consequences (for communication and travel) of a sample of DCN uses; and a Communications/Travel (C/T) Log, in which respondents tallied each instance of communication in each of numerous categories (phone, e-mail, fax, document, in-person, and so on), over a four-consecutive-day period, once before and once several months after beginning to use DCN.

Analysis of the Activity Diary data (148 respondents; 636 uses of DCN) suggested that the net impacts of DCN were to: greatly increase the number of electronic communications; leave the number of in-person communications essentially unchanged (generating some communications, but eliminating or substituting just as many); decrease the number of communications through physical objects (such as a book or diskette); and decrease the number of trips (Balepur, 1997). Hence, the overall impact of DCN as far as travel is concerned appears to be one of substitution.

However, Balepur points to several limitations in the data. Again, it is primarily respondents' impressions (in this case, of hypothetical consequences of real behavior) which are being obtained. When they reported the likely consequences of the DCN use in question (e.g., generating a trip), they could have been thinking of just the immediate consequences or of the chain of consequences extending into the indefinite future. The number of times a consequence was expected to occur was not reported, so 'generating a trip' may have meant one trip in one case and five in another. The same issue of the proper attribution of causality which was discussed in Section 3.4 applies here as well: it was very easy for respondents to confuse 'using' DCN with 'caused by' DCN, when the two are not necessarily the same.

Further, this part of the analysis is essentially an example of the application-specific approach described in Section 3, where the application is Internet access. DCN, viewed alone, may reduce travel and increase electronic communication, but the net impacts of *all* modes on each other cannot be ascertained by taking only DCN uses as the focal point. A different picture emerges in the analysis of the C/T Logs, which more closely embodies the spirit of the activity-based approach. The latter analysis identifies changes in communications patterns, not solely due to DCN,

but any changes that occurred over the approximately six months (on average) between the before and after measurements.

Before and after logs for 108 respondents provided data for the estimation of a six-equation system, in which the endogenous variables were the daily average numbers of communications (sent and received by the respondent) involving each of five modes (phone, fax, e-mail, physical object, and personal meeting), and the number of trips made by the respondent. Exogenous variables included elapsed time between the before and after measurements (which varied across the sample), seasonal dummies, and socioeconomic characteristics. Preliminary results (Meenakshisundaram and Mokhtarian, work in progress) are that: the elapsed time variable is significant and positive in all equations except for number of communications by physical object, meaning that each form of communication is generally increasing over time; (again, except for the physical object equation) the amount of communication by each mode in the after wave is positively related to the amount by the same mode in the before wave; and most significant 'cross-mode' relationships (impacts of the amount of communication by one mode on amounts by other modes) are positive rather than negative.

Taken together, these results suggest that complementarity rather than substitution is the predominant impact. The fact that an apparently different result is obtained from a broader look at (nearly) all communication activity than when the focus is on a particular type of communication is provocative, lending support to the supposition that the application-specific results discussed in Section 3 are necessarily incomplete.

Advantages and disadvantages: The activity-based approach theoretically combines some of the strengths of the other two methods - comprehensive coverage with behavioral insight, at the level of the individual decision maker. On the other hand, it presents a number of measurement difficulties which make it an imperfect solution in practice. For example, typical activity or time-use diaries would need to be modified to focus on the desired modes of communication, and the level of detail needed to perform the desired analyses might be tedious for the respondent.

Further, in such data collection instruments the unit of measurement is normally *time* spent on each activity (as well as simply *number* of activities). Other units of measurement are important, however. One such unit is the *quantity of communication* involved: 15 minutes spent reading the newspaper transfers considerably more information than 15 minutes spent writing an e-mail message. But transforming disparate modes of communication into a common denominator of quantity is problematic to say the least. The *quality* and *value* of the communication are also important dimensions, as the same example illustrates (the smaller quantity of information transferred through the e-mail message may have a higher value). These dimensions present even greater measurement challenges. Also, to properly analyze impacts on travel (trips, distance, mode, time of day, and so on) requires that, for each trip made, the diary collect information which is at a higher level of detail than is found in most activity or time-use diaries.

Finally, this approach is likely still to be most commonly applied on a short-term (months or a year) rather than on a long-term basis, although obtaining panel data over a longer period of time (several years) is certainly possible in theory.

5. MODELING THE CHOICE OF AN ACTIVITY MODE

This review paper has focused on empirical studies directly addressing the relationship between telecommunications and travel. To date, most of those studies have evaluated the impact of telecommunications, *given* an activity pattern. Regardless of which of the three approaches discussed in this paper are taken, all of the studies which permit an assessment of complementarity or substitution to be made represent essentially accounting exercises. The micro-scale approaches are oriented toward comparing the number of trips (or distance traveled) generated to those reduced to obtain a net impact, whereas the macro-scale approaches compare aggregate expenditures on travel to those on communications, whether cross-sectionally or over time. These calculations are only indirectly undergirded with conceptual models of choice among communication alternatives.

On the other hand, the literature also contains a number of behavioral models of telecommunications-based choices, which have not been thoroughly reviewed here. In telecommuting, there are behavioral models of preference for the home-based form (Bernardino and Ben-Akiva, 1996; Bernardino *et al.*, 1993; Mokhtarian and Salomon, 1997) and between the home- and center-based forms (Bagley and Mokhtarian, 1997; Stanek and Mokhtarian, 1998), choice of home-based telecommuting (Mokhtarian and Salomon, 1996b), frequency of home-based (Mannering and Mokhtarian, 1995; Sullivan *et al.*, 1993; Yen and Mahmassani, 1995) and center-based (Ho, 1997) telecommuting, and duration of center-based telecommuting (Ho, 1997). There are models of choice between various forms of communication in a business context (Fischer *et al.*, 1992; Hauser, 1978; Moore and Jovanis, 1988). And there are models of teleshopping behavior (Koppelman *et al.*, 1991; Manski and Salomon, 1987; Timmermans *et al.*, undated).

The demand for information generates communications activities. Analogously to trip generation, distribution and modal choice, the demand for information can also be satisfied by different quantities, at different destinations and by different modes. However, this comprehensive conceptualization and the development of (mathematical) models that explain the broader communications behavior have so far received only scant attention.

Some suggestions have been presented, but, unfortunately, not pursued sufficiently yet. Moore and Jovanis (1988) have suggested an integrated framework that includes the generation and type of communications activities, which then leads to the choice of either travel or telecommunications. Ben-Akiva *et al.* (1996) have also suggested that IT options be integrated into the spatial choices structure, both at the level of offering alternative activities and in supplying information for short term decisions.

Starting from this literature and the foregoing discussion, a prototypical model of activity 'mode' choice begins to emerge. Given the demand for a particular type of activity (such as work, or shopping, or conducting a business communication), the individual evaluates alternative ways or modes of performing that activity. Generically, we can refer to a location-based alternative L (requiring travel) and a telecommunications-based alternative T (potentially not requiring travel, or requiring less), but of course in specific applications there may be several variations on these categories.

We have frequently pointed out that a given activity (such as shopping) may fulfill a number of purposes in addition to the primary or most apparent one (making a purchase). This means that the

individual will choose between alternative activity modes based on a variety of relevant dimensions, and thus that the analyst should characterize each mode in terms of those dimensions and measure the individual's evaluation of each mode on each dimension. Generically, the utility of an individual for an activity mode could be viewed as a function of the following variables or dimensions (where each is both individual- and mode-specific unless otherwise indicated):

- the quantity, quality, and timeliness of information obtained by the individual (quality is likely to be superior for L compared to T, whereas the winner on quantity and timeliness may depend on the situation);
- the quantity, quality, and/or timeliness of the activity completed by the individual (being more productive working from home is an example in which T is superior here, but examples in the opposite direction can also be constructed);
- the social/psychological content (possibly superior for L);
- the physical exertion required (higher for L, but that may be a positive trait for some individuals some of the time);
- the aesthetic content (may be higher for L, e.g. when travel to a conference is chosen because of its scenic venue; or higher for T, e.g. when one has a nicer office and/or view at home than at the regular workplace);
- other positive qualities specific to the context;
- travel cost/time/stress (potentially zero for T, but anyway presumably favoring it);
- telecommunications costs (potentially zero for L, but anyway presumably favoring it);
- other situation-specific costs and constraints;
- personal characteristics of the individual;
- mode-specific constant(s); and
- unmeasured variables (error).

Using this framework, it is easy to see how the individual's utility-maximizing choice between T and L for conducting the activity depends on the relative advantages of each alternative on the relevant dimensions (i.e. the values of the explanatory variables), and on how those dimensions are weighted or traded off by the individual (i.e. the coefficients of those variables as estimated from the data through maximum likelihood or some other means). The travel impacts of the collective choices made by a given sample (or population) can then be calculated. Assuming that distance (or travel time, cost, or some other measure of spatial separation) is a dimension relevant to the choice and hence is measured for each alternative (often zero for T), the expected travel impacts can be obtained by multiplying the travel outcome (distance, time, cost, etc.) for each alternative by the estimated probability of choosing that alternative, and summing across the sample (or population).

As initially described here, the alternatives apply to a single activity and hence are application-specific. However, it may be possible to design more complex alternatives involving the choice of a pattern of activities across, say, a day, and hence to model the transportation impacts more comprehensively.

6. SUMMARY AND DIRECTIONS FOR FUTURE RESEARCH

To the simple question: Do telecommunications make a difference? we can probably answer affirmatively with a high level of confidence. However, if the underlying assumption is that 'difference' implies substitution, the answer must be qualified.

The differences telecommunications make are diverse, as shown in Table 2 which summarizes the results discussed here. As has been noted throughout this paper, the relationship between telecommunications and travel can be of several basic types: substitution, stimulation, modification, and neutrality. Despite the widespread expectations of a substitution effect of telecommunications for travel, it may be just part of a more complex relationship. In fact, it is very likely that much of the impact is in the form of modifications in travel patterns (Salomon, 1985), such as trip timing, destination change, coupling with other users or a change of mode of travel. It may also be the case that some constraints are relaxed (or vice versa) and that travel-based activities are changed, as a result. Furthermore, as noted above, telecommunications may change land use patterns, and as a result, modify travel. So, there seems to be a variety of differences introduced by the availability of telecommunications-based activities.

Table 2: Summary of Empirical Results

Approach	Dominant Empirical Result
Macro-scale comprehensive	
Consumer	substitution
Industry	complementarity
Micro-scale limited	
Telecommuting	substitution
Teleconferencing	complementarity
Teleshopping	no results to date; approximately neutral impact expected
Telephone	mixed, ambiguous
Micro-scale comprehensive	complementarity

As indicated in the previous section, we have on the one hand the 'accounting' studies, which take a given set of telecommunications-based activities and attempt to calculate the net impact on travel, and on the other hand the 'modeling' studies, which attempt to understand the individual decision process and inform a demand forecast. Improvements are possible in both cases. For the studies of net impact on travel, it is clear that research will benefit from the further accumulation of empirical evidence and the growing availability of data. Data collection efforts must be carefully designed to produce the input necessary for rigorous research. That is true for micro-level as well as for macro-level analyses which may complement each other.

But, the more significant gains are to be expected from further development of conceptual and theoretical models of communication choice behavior. Much of the modeling research done to date relies on stated preference (SP) approaches, which are very suitable to situations in which revealed preference is difficult to observe, or nonexistent, as may be the case with new technologies. However, despite considerable advancement in applying SP methods in recent years, their reliability is inherently attenuated when the behavior considered is unfamiliar to the respondents. There is much evidence that telecommuting, for example, is far more often preferred than chosen (Mokhtarian and Salomon, 1996a). While doubtless some of this gap is due to genuine constraints on a genuine desire to telecommute, it also appears that in many cases the expressed preference is a weak one which may disappear entirely as the disadvantages of telecommuting are made more apparent. In general, much of what people believe about the impacts of information technology is derived from futuristic notions, which in turn, tend to overemphasize substitution effects (Salomon, forthcoming). Thus, future modeling research will also benefit from the growing availability of revealed preference data.

Further, the prevailing modeling research approach which has focused on specific applications, resembles the early, and now almost obsolete interest in particular trips, classified by trip purpose. Future research should broaden the view.

Spatial behavior, in our current understanding, assumes that individuals (or households or firms) generate a demand for activities. This demand is translated into travel which can, for practical purposes, be simplified into a set of behavioral choices, modeled as a sequential or simultaneous process of trip generation, trip distribution, modal choice and route choice. The demand for activities is conventionally assuming a spatial distribution of opportunities, which is a reflection of the land-use map. The emergence of aspatial opportunities for performing various activities calls for more attention to the nature of the activities, and their subsequent implications for behavior.

Thus, the currently-prevailing micro-scale application-specific models, which combine a conceptual model of choice behavior with an empirical context are necessary building blocks for further development of causal models which explain *communications and spatial activity* at the disaggregate level. If the past experience in activity modeling and in telecommunication - travel modeling can be a lesson, then the complexity of the tasks ahead is enormous, but nevertheless necessary.

While some of the attributes of the demand for physical activities are quite well recognized (more so in the case of work, less so in the case of shopping and leisure), the attributes of the demand for information, and consequent communications activities, are presently less apparent. Their

temporal, spatial and other attributes need to be better understood before comprehensive models can be developed.

For example, the transportation-telecommunications issue has focused to a great extent on the impacts of the latter on distance or space, culminating in *The Economist* cover story on the "Death of Distance" (Sept. 29, 1995). However, the research reviewed above may in fact warrant a shift in the focus from space to time. As activities are inherently performed in both time and space, focusing primarily on space may be too narrow a view of the potential impacts of telecommunications. We suggest that much of the impact on travel patterns is moderated through the time-saving (rather than space-saving) capability of telematics and the consequent reorganization of activities along the temporal dimension.

One particularly troublesome problem in this general type of research is the role of values and norms. It is reasonable to assume that norms can change as younger generations adopt and assimilate information technology. It is not clear, however, how this will affect their behavior in a few years time. The very least that current students of the field need to do is to identify the often implicit value- and norm-laden assumptions in current models. This requires a critical assessment of the current models.

Two hypotheses which seem to emerge from the current state of the art are suggested. First, it would be interesting to study the adoption of activity modes in a cross-cultural context. One can hypothesize that in some cultures there will be greater acceptance than in others of electronic forms in lieu of face-to-face communications. Such differences may be attributed to the importance associated with personal contact and/or attitudes toward technology. (Similar differences may also be found across sectors in the economy).

Second, there is a growing body of literature suggesting hypotheses about the positive utility of travel (e.g., Maggi *et al.*, 1995; Salomon and Mokhtarian, 1997). If people differ significantly in their attitudes towards travel then they are likely to differ in their propensities for substitution and complementarity. If this is the case then the understanding of the impacts of telematics on travel really depends on travel attitudes which should be the focus of detailed hypothesis testing.

Ultimately, however, it will not be sufficient simply to develop better models of activity choices. It is important to remember that, from the perspective of the transportation professional, the demand for the activity-based approach is a derived demand -- derived from our need for more accurate transportation modeling. Achieving an understanding of the activity decision process for its own sake is commendable, but ultimately (where the rubber meets the road, so to speak) there will still be a real transportation network for which it will still be important to forecast link volumes by mode and time of day. Any approach which does not allow that ultimate outcome, or which stops short of obtaining it, will be of limited use in a regional planning context.

Hence, what is needed is a combination of the accounting and modeling approaches. In the short term, it may be possible to synthesize insights gained from both methods to develop aggregate, application-specific forecasts. This is the approach taken by Mokhtarian (1998), in which she used both behavioral modeling results and empirical evidence on net impacts to forecast the future systemwide effects of telecommuting on travel. In the long term, however, the desired goal is a comprehensive, integrated, completely behavioral model of communication and travel choice,

leading to causally-based aggregate forecasts of the transportation outcomes. The generic approach outlined in the previous section may be a fruitful direction forward.

We do not know at this point in time how much substitution and how much stimulation of travel is taking place. What we are uncovering is mostly the complexity of the interactions of telecommunications with the already complex phenomena of activity and travel behavior.

Will we know in the future? That depends very much on how successful we are at developing the comprehensive analysis approach suggested above. None of the approaches taken so far achieve the desired ideal, but they are nevertheless still of considerable value. It's just that we should not fail to keep the fore(ca)st in mind while working on the trees.

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