Accessibility and ICT: A review of literature, a conceptual model and a research agenda

Bert van Wee
Delft University of Technology
g.p.vanwee@tudelft.nl

Caspar chorus
Delft University of Technology
c.g.chorus@tudelft.nl

Abstract

Over the past two decades many papers are published in the area of ICTs impact on travel behaviour. Literature focusing on the impacts of ICT on accessibility is relatively scarce. In this paper we give an overview of impacts of ICT on four components of accessibility as distinguished by Geurs and Van Wee (2004): (1) the land-use component, (2) the transportation component, (3) the temporal component, and (4) then individual component. Conclusions are firstly that much more literature exists on the (potential) impacts of ICT on travel behaviour than on its impact on accessibility. Secondly, we argue ICT potentially has an impact on all four components of the concept of accessibility. Thirdly, there seems to be a major challenge in developing accessibility measures and indicators that include ICT, including those that measure the utility of accessibility. Fourth, in the area of ICTs impact on travel behaviour, many research gaps exist. Examples are the impact of ICT on *overall* activity and trip patterns, impacts of ICT on activities and trips at the household and social network level, ICT as a means to avoid congestion or mitigate its effects, and the role of the phenomenon of self-selection in the context of ICT use. Finally, a challenge for modelling exists: we think a major challenge is to develop models for activities, including ICT-impacts, that combine high levels of behavioural realism with (econometric) tractability. In this regard it should be noted that for practitioner, behaviourally realistic models that are very hard to calibrate or validate, let alone communicate to policy-makers and practitioners, are of limited value.

KEYWORDS: ICT, accessibility, travel behaviour

1.   Introduction

A paramount goal of transport policy is to improve accessibility: the transport system should allow people to travel and participate in activities, and firms to transport goods. However, despite the crucial role of accessibility in transport policy-making throughout the world the concept is generally poorly defined. Indicators often relate to the transport system only; travel times, time losses due to congestion, and congestion chances being example indicators. this narrow-minded approach ignores that several other useful categories of indicators for accessibility exist. Geurs and Van Wee (2004) argue that proper definitions of accessibility generally should have (at least a selection out of) four components: (1) a land-use component, (2) a transportation component, (3) a temporal component, and (4) an individual component.

It is now generally recognized that ICT in its several forms may have an impact on activity patterns and travel behaviour, along the lines of the four components of accessibility as distinguished by Geurs and van Wee (2004). For example, shops might relocate due to selling increasingly via internet, influencing people's location choices if they visit these shops (location component). If people work at home using ICT for some hours and then commute, travel by time of day may change, in turn leading to changed travel times, and less congestion during peak hours (transport component). ICT might also change the time pattern of activities. E.g. one can choose a product via the web at night even if shops are closed (temporal component). It should be noted that the use of ICT for several purposes is characterised by high levels of inter-individual heterogeneity. E.g. young people generally more easily adopt new individual ICT technologies, such as navigation systems, than do older people (individual component).

In this paper we argue that ICT potentially has many impacts on activities and travel behaviour and its externalities (related to safety, congestion and the environment), on all accessibility related components presented above, and that many of these impacts are poorly addressed in literature. Furthermore, we aim to give a systematic overview of potential impacts of ICT on accessibility. To the authors' knowledge no such comprehensive overview of ICTs impact on accessibility exist. As a final contribution we address gaps in literature in the area of ICTs impact on travel behaviour and accessibility.In sum: the aims of this paper are to (1) give an overview of potential impacts of ICT on accessibility resulting in a conceptual model for ICTs impact on accessibility; (2) to address challenges for future research in the area of ICTs impact on accessibility.

The scope of this paper is defined as follows: we exclude ICTs' impact on goods transport though this impact is also very important, and though ICTs impact on goods transport also affects passenger transport related accessibility (Weltevreden and Rotem-Mindali, 2009). However, some of the categorisations and ICT impacts as described in this paper also apply to goods transport, the use of navigation systems being an example. In addition, we exclude from our analyses access to ICT (e.g. Pick and Azuri, 2008). Note that we do not review the literature by systematically presenting results in table forms; rather, we include references in our line of reasoning, following the accessibility components of Geurs and Van Wee (2004).

The remaining part of this paper is organized as follows. Section 2 presents an overview of literature in the area of ICT and travel behaviour. Section 3 gives an overview of literature in the area of accessibility. Section 4 then describes the potential impacts of ICT on accessibility. Section 5 presents a conceptual model for ICTs impact on accessibility. Section 6 finally presents the main conclusions of the paper.

2. An overview of literature on ICTs impact on travel behaviour

This section presents an overview of literature in the area of ICTs impact on travel behaviour, clustered in a few categories of literature.

ICT and activities: Substitution versus generation

Transport policy-makers have often hoped for substitution of travel by ICT. Notwithstanding high expectations, much of the early substitution optimism is reduced over time, one explanation being, as several authors have addressed, the preferences of people for face to face interactions (e.g. Graham and Marvin, 1996). In addition, it has been well documented

that ICT could also trigger generation of travel. Its impact on generation of additional travel might even be more important than the substitution effect. For example, Mokhtarian and Meenakshisundaram (1999) conclude that it is unlikely that ICT reduces travel significantly. Probably partly because of high expectations of substitution effects, early research on the impact on ICT on travel behaviour and activity patterns generally focused on issues like substitution versus generation of commuter travel (e.g. Mokhtarian and Salomon, 1997; Mokhtarian and Krishna, 1998). This focus was followed by a growing interest in shopping related travel and activities (e.g. Ferrel, 2004; Rotem-Mindali and Salomon, 2007; Farag *et al.*, 2007; Weltevreden and Rotem-Mindali, 2009), and wider impacts of ICT on activities, such as e-banking (e.g. Weltevreden *et al.*, 1996) and business travel (e.g. Aguliera, 2008). Nowadays it is generally recognized that ICT potentially has an impact on all kinds of activities, not only jobs and shopping, but also recreation and so forth (Muhammed *et al.*, 2008). An example of research into substitution of travel by ICT is found in De Graaff and Rietveld (2007) who focus on substitution between working at home and out-of-home. They conclude that working at home and out-of-home act as (slightly imperfect) substitutes, largely depending on characteristics of the individual. That is, working at home and out-of-home seems to be more determined by individual characteristics than by (changes in) commuting time and ICT availability. An example of the nowadays generally accepted concept of complementarity of ICT and travel can be found in Farag *et al.* (2007), who carried out a study on shopping online and/or in-store. They found that searching online positively affects the frequency of physical shopping trips, which in its turn positively influences buying online. In addition it was found that e-shopping could be task-oriented for some people, and leisure oriented for others. It should be noted here that communication technology cannot fully compensate for the richness of face-to-face contacts, in cases suc as, for example, the conveyance of complex, non-structured, or potentially ambiguous information (Boden and Molotch, 1994; Larsen et al., 2007; Aguilera, 2008).

More recent research has emphasized that new ICT services and applications do not have a clear-cut functional equivalent in the 'physical' world, like many of the earlier ICT technologies had. This puts the substitution versus generation discussion into another perspective (Hjorthol and Gripsrud (2009): new ICT services and applications, such as word-wide e-gaming, might be just another activity that people might carry out, in stead of, e.g. reading a book or watching TV.

Multitasking, fragmentation

Kenyon and Lyons (2007) argue that activity impacts of ICT will not be fully understood if multitasking is ignored. In an empirical study it was found that *all* participants report multitasking at some stage during a surveyed week. The authors note that the categories of activities in which time use is most underreported when primary activities alone (and not less important simultaneously carried out activities) are considered are those that have been hypothesised to be susceptible to travel substitution effects, because of their propensity to be performed using ICTs: communicating; entertainment/recreation; information search; and shopping. They found that for 84% of the time that an individual is travelling, (s)he will be conducting at least one parallel activity.

In a related study, Lenz and Nobis (2007) argue that ICT leads to a reorganization of activities in time and space, thus having as a consequence impacts on travel behaviour. They discuss the concept of "fragmentation" as earlier introduced by Couclelis (2004) and conclude that transport demand increases by the fragmentation of activities. They distinguish between spatial fragmentation (fragmentation of activities over different locations, temporal fragmentation (fragmentation of activities over time) and fragmentation of the manner in

which activities are performed (activities themselves can be carried out in more ways, e.g. shopping physically versus e-shopping). Based on their empirical findings it is not clear whether the use of ICT leads to an increase of travel demand for people who already made a lot of travels before the diffusion of ICT, or whether ICT has a small reducing effect on the very high mobility level of these people.

Travel mode-, route- and departure time choice

Another category of impacts of ICT on accessibility relevant subjects is its impact on mode- route- and departure time choices. For example, out-of-vehicle systems such as dynamic information panels showing route information may affect peoples' route choice and reduces travel times by optimizing the use of road networks. As another example, in-vehicle (satellite navigation - satnav) systems may allow people to reduce travel times, and to reduce search time for route information (substitution of route searching via the web by satnav systems).

Here, an evolution in expectations has occurred concerning ICTs' potential to help achieve policy goals, that is similar to the one described in the context of telecommuting and e- shopping. That is, initial expectations that ICTs would greatly contribute a to more efficient use of transport infrastructure by spreading travellers across modes, routes and departure times (e.g. Commission of the European Communities, 2001; Federal Transit Administration, 2003; Department for Transport, 2004) have recently been downwardly adjusted by a stream of theoretical and empirical research (e.g. Chorus et al., 2006a, b). The main message conveyed by these studies is that because information acquisition is costly in terms of time, effort, attention and (sometimes) money, travellers often ignore available information. See, for example, a study by Chatterjee & McDonald (2004) that shows that awareness levels of information provided through Variable Messgae Signs can be as low as 33%. On a more positive note, a recent laboratory study found that information provision does lead to modest increases in travel choice quality, especially when the information makes travellers aware of travel alternatives that were previously unknown to them (Chorus et al., 2007a).

Social impacts

Another category of literature focuses on the social impacts of internet use and activities. Internet use has been linked with negative social effects, including reduced social interaction and reduced quality of the activity experience (Kraut et al., 1998; Kenyon and Lyons, 2007). However, see Kraut et al. (2002) for a differing opinion, which signals that the debate about ICTs' social impact is not yet closed.

Accessibility

Most of the literature on ICT and travel relates to travel and activities. We found much less literature in the area of the impact of ICT on accessibility. Job accessibility probably still is the most often researched topic in the area of ICT and accessibility. Examples include Muhammed *et al*. (2008) who developed a model that integrates ICT-based and physical job accessibility, and Shaw and Yu (2009) who extended the time-geographic approach of individual activities by including the virtual space.

3.   Accessibility: an overview of literature

Several authors have written review articles on accessibility measures, often focussing on a particular category of accessibility, like location accessibility (e.g. Song, 1996; Handy and Niemeier, 1997), individual accessibility (e.g. Pirie, 1979; Kwan, 1998) or economic benefits of accessibility (e.g. Koenig, 1980; Niemeier, 1997). Here we use the review of Geurs and Van Wee (2004), from here on GvW, as a point of departure. Their review differs from other

review articles, firstly because accessibility measures are reviewed from different perspectives (land use, transport, social as well as economic impacts), instead of focusing on one specific perspective. Secondly, measures are reviewed according to a broad range of relevant criteria, i.e. (a) theoretical soundness, (b) interpretability and communicability, (c) data requirements, and (d) usability in social and economic evaluations. We consider this approach as a useful point of departure to understand potential ICT impacts on accessibility. GvW define accessibility - as far as persons are concerned - as the extent to which land-use and transport systems enable (groups) of) individuals to reach activities or destinations by means of a (combination of) transport modes(s). Note that we exclude goods transport in this paper, and therefore also in the definition we use for this paper. Note that GvW use the term accessibility whey using a locations perspective, as opposed to access that assumes a person's perspective. In other words, a location is accessible by persons, a person has access to locations. ICT can have an impact on both accessibility and access. E.g. the accessibility of a city centre can increase due to ICT based dynamic parking information systems, increasing access of individuals. In this paper we use the term accessibility for both the location and the person's perspective.

As already mentioned in the introduction GvW distinguish four components of accessibility that they derive from literature:

- The land-use component reflects the land-use system, consisting of (a) the amount, quality and spatial distribution of opportunities supplied at each destination (jobs, shops, health, social and recreational facilities, etc.), (b) the demand for these opportunities at origin locations (e.g. where inhabitants live), (c) the confrontation of supply and demand for opportunities which may result in competition for and among activities with restricted capacity such as job, labour force, and school vacancies and hospital beds (Van Wee *et al.*, 2001).

- The transportation component describes the transport system, expressed as the disutility experienced by an individual when covering the distance between an origin and a destination; included are the amount of time (travel, waiting, parking), costs (fixed ad variable) and comfort-related variables (such as reliability, level of comfort, accident risk, etc.). This disutility partly results from the confrontation between supply of and demand for infrastructure capacity. The supply of infrastructure includes its location and characteristics (e.g. maximum travel speed, number of lanes, public transport timetables, travel costs). The demand relates to both passenger and freight travel.

- The temporal component reflects the temporal constraints, i.e. the availability of opportunities at different times of the day, and the time available for individuals to participate in certain activities (e.g. work, recreation). Note that this temporal component enjoys a rapid increase in popularity among academics in transportation and geography (e.g. Ettema et al., 2007; Schwanen & Kwan, 2008).

- The individual component reflects the needs (depending on age, income, educational level, household situation et.), abilities (depending on people's physical condition, availability of travel modes etc.) and opportunities (depending on people's income, travel budget, educational level, etc). of individuals. These characteristics influence a person's level of access to transport modes (e.g. being able to drive and borrow/use a car) and spatially distributed opportunities (e.g. have the skills or education to qualify for jobs near their residential area), and may strongly influence the total aggregate accessibility result.

GvW state that these four components interact. E.g. the impact of temporal constraints, such as opening times of shops, on an individual might be less important if she belongs to a household with another member who can do the shopping. Next, GvW state that an accessibility measure should ideally take all components and elements within these

components into account, although in practice applied accessibility measures focus on one or a selection of components only. GvW identify four categories of measures for accessibility: (a) infrastructure based measures, including level-of-service indicators such as travel speeds an congestion levels, (b) location-based measures, analysing accessibility at locations, typically on a macro-level, an example being contour measures such as the number op jobs accessible by car within 30 minutes, (c) person-based measures analysing accessibility at the individual level (based on space-time geography of Hägerstrand, 1970), and (4) utility-based measures, analysing the economic benefits that people derive from access to spatially distributed activities.

Since the publication of the paper of GvW we think three developments are of importance to understand the current state of the art in accessibility measures and its applications. Firstly, and directly related to the aims of this paper, it should be noted that the definition used in GvW is related to physical accessibility only. In recent years ICTs impact on travel behaviour and - though not explicit - accessibility has gained increasing attention, as reflected by the special issue on the interaction between ICT and human activity-travel behaviour in Transportation Research part A (for the editorial: see Kwan et al., 2007; see references to papers elsewhere in this paper). And the special issue in the Journal of Transport Geography (Lyons, 2009; see references to papers elsewhere in this paper). Secondly progress has been made in the area of the utility-based measures, in particular the logsum-based measures (see De Jong et al. (2007) for an overview). The logsum approach allows the researcher to relatively elegantly derive the utility of accessibility from the logsum of random-utility based discrete choice travel models. Since the conceptual idea that the logsum can be interpreted as an accessibility-measure was launched (Ben-Akiva & Lerman, 1985), it has been frequently used in academia (see Dong et al. (2006) for a recent example), though being less popular among practitioners. Recently, appreciating that the econometric assumptions underlying the most basic logsum-formulations (specifically, the presence of iid errors) may often be too restrictive, many researchers have proposed ways to relax those assumptions while maintaining closed form solutions (e.g., Daly & Bierlaire, 2006) or at least tractable formulations that can be solved by means of simulation (e.g. Cherchi & Polak, 2005; Zhao & Kockelman, 2008; Fosgerau & Bierlaire, In Press). Next to this progress in terms of econometric specification, there has been attention for the behavioral assumptions underlying the Logsum-approach to measuring accessibility: Chorus et al. (In Press) show how Logsum-based measures of user benefits associate with changes in the transport system (such as increases in accessibility) can be extended to allow for limited awareness among travelers.
.Thirdly, progress is made in the person based measures. E.g. Dong et al. (2006) introduced a measure that measures accessibility to all activities in which an individual engages, incorporating constraints such as scheduling, and travel characteristics such as trip chaining. Veldhuisen et al. (2005) and Arentze et al. (2008) contributed to the practical applicability of such measures showing the possibilities of synthetic data, reducing the huge barrier of the enormous data collection effort that these measures normally need. Nevertheless, we think the review of GvW is particularly of interest for the aims of this paper because it gives a structured overview of the components that potentially can be influenced by ICT. Before elaborating on the potential impacts of ICT on accessibility we first give an overview of ICT that could potentially be relevant from an accessibility perspective.

4.   Potential impacts of ICT on accessibility

If one wants to categorize ICT in the context of its impact on travel behaviour, a major challenge is to select the primary key for categorization. Examples of such keys include: Information technologies versus Communication technologies. ICT having trip based impacts

versus activity based impacts, portable versus non-portable ICT devices, personal devices versus non-personal ICT. Here we use a hybrid categorization by distinguishing between three types of ICT:

- PC use at fixed locations for information and communication;
- Individual mobile devises, such as laptops and PDAs for information and communication;
- Infrastructure related information provision technologies, such as Dynamic Route Information Panels (DRIPS) for roads and public transport travel information.

We will argue that these three types of ICT can have impacts on all 4 components of accessibility as presented in GvW. We discuss ICTs impacts on accessibility distinguishing these components.

Transport component

ICT can reduce travel resistance in many ways. Firstly, a traveler may access travel information before the trip is available via individual ICT devices (PCs, PDA's and the like). This can be done via web based information (PC at fixed locations or portables), or via mobile devices. Due to the information the traveller can leave the origin 'just in time' reducing access time. In addition, the 'optimal' route can be selected for several modes (car, public transport, air travel) as well as for multimodal travel. Note that transport resistance is not the same as travel time. We use Generalized Transport Costs (GTC) as the term to express transport resistances. So, the traveller might select a way to travel resulting in a longer travel time (compared to what she would have done without the use of ICT) but in lower GTC, e.g. because she does not need to change trains or because the air ticket is cheaper. Pre trip information can relate to the regular time tables, but also to disturbances, e.g. related to accidents on roads or rail, or delays in case of flights. A recent empirical study by Chorus et al. (2007a) shows how travel information may impact multiple components of GTC at the same time, leading to higher levels of accessibility.

Secondly, ICT can help reduce travel resistance while travelling by providing on route information via individual mobile sources. Here we define 'on route' as: after the moment the traveller starts travelling. E.g. in case of delays in public transport she might be able to find out if another way of continuing the trip is to be preferred over the original plan. Examples include leaving the train at an intermediate station to switch to the bus, or the decision to walk from the final station to the destination in stead of waiting for a delayed bus. In case of car use satellite navigations (satnav) systems can provide information on (unexpected) delays and advise another route. If the traveller decides to change the travel plan, her GTC will very likely (but not necessarily) decrease compared to the way of travel without ICT. Note that on trip information can be obtained initiated by the traveller, but technology also can provide information not explicitly asked for, such as sending an SMS because of an unexpected delay. Interestingly, travellers have been recently found to prefer such early-warning information over information that forces them to take the initiative, in the context of frequently made trips such as commute trips (Chorus et al., 2007b).

Thirdly, ICT can help reduce travel resistance while travelling via non-individual infrastructure based ICT. DRIPS can provide information on expected travel times in case of competing routes, including delays. DRIPS can also give information on train options. E.g. on a motorway in the South of the Netherlands travellers receive information on train connections to the Randstad area (the densely populated Western part of the Netherlands, including cities like Amsterdam, Rotterdam, The Hague and Utrecht). At public transport nodal points (such as stations) DRIPS can give dynamic information on bus, tram, or metro connections, as well as no train connections. We consider the ICT use that informs the

railway personnel to be also an example of this category: thanks to ICT the train personnel can provide the travellers with travel information via train speakers.

Following the concept of GTC we include any impact of travel resistance, not necessarily only travel time and costs related. In addition the comfort of the traveller matters. We think ICTs impact on comfort is a relatively under-researched area of research. Below we give some examples of the impact of ICT on comfort. Firstly: even without any change in travel times or costs, the traveller might appreciate receiving information on delays, so that she can phone, email, or SMS to let know people at the destination side of the trip she is delayed. Secondly, she might change activities while travelling because she knows about delays. Assume a train traveller should arrive at a station in 10 minutes. This might be too short to decide to start working using a laptop. But if there is a serious delay and she knows the train trip will take an additional 45 minutes, she might decide to start working using her laptop. Thirdly, route information might increase comfort even if no change in routes is made because of ICT use, because the traveller might appreciate knowing she has chosen the 'right' route. In general, the importance of these aspects follows from the notion that travelers dislike uncertainty per se (i.e. are risk averse). The existence of this dislike of uncertainty has been well documented in the context of travel time uncertainty (e.g. Lam & Small, 2001; Bates et al., 2001; Rietveld et al., 2001; Brownstone & Small, 2005;) as well as travel costs uncertainty and uncertainty about waiting times (e.g. Chorus et al., Forthcoming).

The land-use component

This component is important at three levels. Firstly, it is generally recognized that the transport system and the land use system interact (e.g. Wegener and Fürst, 1999). If thanks to ICT transport resistances reduce, land use changes can be expected. E.g. it might impact locations for new office areas, or shops. Secondly, ICT may have an impact on the distribution of actors over the given locations of destinations. In this case land use itself is not influenced by ICT but the distribution of, for example, households over houses, companies over offices, or companies over industry areas (see Argiolu et al. (2008) for a case study into this latter type of ICT impact, focusing on Intelligent Transportation Systems). Thirdly ICT might have an impact on which persons carry out which activities at which locations. This third category can be split in subcategories: a person (or household) may change (a) activities, (b) locations of activities. Examples of (a) include decisions not to visit friends or family because of a road accident resulting in long delays, the decision to meet someone after ICT based contacts, and the decision to bring children to school because the person works at home using ICT in stead of at the office. Examples of (b) include the decision to work at home using ICT in stead of travelling to work, and the decision to buy a second hand car at another dealer, found via the web. Though not based on empirical evidence we have the impression that in particular the impact of ICT on non-work related activity and destination choices is potentially large, and certainly under-researched. for example, thanks to ICT people are aware of concerts over a large area, new or second hand goods; people meet other persons using ICT that they then might want to visit, select other holiday destinations, etc. ICT therefore certainly can have an impact on non-work related activity and travel behaviour, and indirectly also on accessibility, via the land use component. Even without the first two categories of ICT impacts (land use changes and distribution of actors over locations), ICT potentially has a large impact on the awareness and valuation of location-based activities at several locations.

The temporal component

As mentioned above the temporal component relates to the availability of opportunities at different times of the day, and the time available for individuals to participate in certain activities (e.g. work, recreation). ICT can have an impact on both. Firstly the availability of opportunities at different times of the day: thanks to ICT a lot of activities can be carried out at other times of day. Nowadays many people work outside the official office hours, e.g. at night or in the weekend, using ICT providing them access to work related networks or connections to colleagues or business partners. In addition via the web people can search for information on products they might wish to buy at any time. Secondly, the time available for activities might change. If ICT allows the traveller to travel more efficiently, she might save time allowing her to spend more time on other activities. Note that the impact of ICT on overall travel time reductions is probably very small, following the theory of constant travel time budgets (e.g. Szalai *et al.* (1972), Zahavi (1979) and Shafer and Victor (1997), Mokhtarian and Chen, 2004). But even if people would decide to use the potential travel time savings thanks to ICT, they certainly appreciate doing so, which in turn increases their accessibility (this is what Jain & Lyons (2008) call 'the gift of equipped travel time'). Note that related utility changes can be estimated easily using utility based measures including the logsum based measures. In addition, ICT can allow a person to save time by combing work and travel, e.g. by using a laptop for work while travelling by train, or by executing business calls while car driving. Note that this impact of ICT has both a transport (resistance) and temporal component.

ICT can also save time because work can be carried out more efficiently. Note that the time savings probably will be used for productivity increases rather than work time reductions.

The individual component

Peoples' wants, needs, preferences and abilities are highly personal. Therefore it is obvious to most researchers that accessibility measures should include the individual component. Following the description of the individual component above, ICT can firstly have an impact on the needs (and wants) of people: people might, for example, want to go to a concert they are made aware of it thanks to ICT. Secondly, ICT can have an impact on the abilities of people. Or maybe better: it can have a positive impact on accessibility in case of limited abilities. E.g. people not able to drive a car (anymore) might be able to travel using ICT for travel on demand, increasing their accessibility. Note that it is increasingly being acknowledged that both the use of new technologies (such as – new forms of – ICTs) and activity-travel behaviour of individuals (and as a result: individual accessibility) is influenced a lot by the social networks in which they participate (see Dugundji et al. (2008) for an editorial of a recent special issue on this topic). However, it remains to be seen whether the increases in behavioural realism associated with incorporating social network-aspects of accessibility outweigh the quite substantial increases in complexity of these studies in terms of both model development and data collection.

Interactions

Following GvW the accessibility components all interact in both ways. E.g. the land use and resistance component interact: transport system characteristics including travel resistances have an impact on land use, and land use has an impact on the transport system. We refer to GvW for a conceptualisation and further description of these interaction. For this paper the message is that literature on ICTs impact on travel behaviour and accessibility addresses (at best) the direct impacts of ICT, but fails to incorporate impacts due to the interactions between the accessibility components.

5.   Towards a conceptual model for ICTs impact on travel behaviour

Previous categorisations and conceptualisations of impacts on ICT focus on travel behaviour. One of the earliest categorizations of ICT's effect is a paper by Salomon (1986) who distinguishes substitution versus complementarity. He subdivided complementarity into *enhancement*, which is the generation of additional travel due to the availability of additional telecommunications, and *increasing efficiency*, which suggests that the efficiency of travel increases by the application of telecommunications, possibly leading to moderate substitution effects - see also Nobis and Lenz (2009). Salomon already in 1986 emphasized that the interactions between telecommunications and travel are two-directional, something that was later confirmed by many others (e.g. Mokhatarian, 2003; Choo and Mokhtarian, 2005). Based on the work of several other researchers, Nobis and Lenz (2009) distinguish between four effects: *substitution*, (telecommunications leading to a decrease in travel demand through a reduction in total number of trips or in trip duration), *complementarity* or *generation* (generation of new trips due to the use of telecommunications), *modification* (change of spatial and temporal characteristics of existing travel patterns by the use of telecommunications) and *neutrality* (no impact of one medium on the other). An often mentioned example of substitution is videoconferencing as a substitute for business travel.

To the authors' knowledge a conceptualisation of ICTs impact on accessibility, focussing on all components as addressed above, does not exist. Figure 1 visualises these impacts, and includes both direct and indirect relationships of ICT.

Figure 1: ICTs impact on the components of accessibility

PC use at fixed location

Mobile devices

Infrastructure technologies

Transport component
Reduce resistance

Land-use component
Land-use changes
Match actors-locations
Match actors-destinations

Temporal component
Availability of opportunities by time
Time available for activities

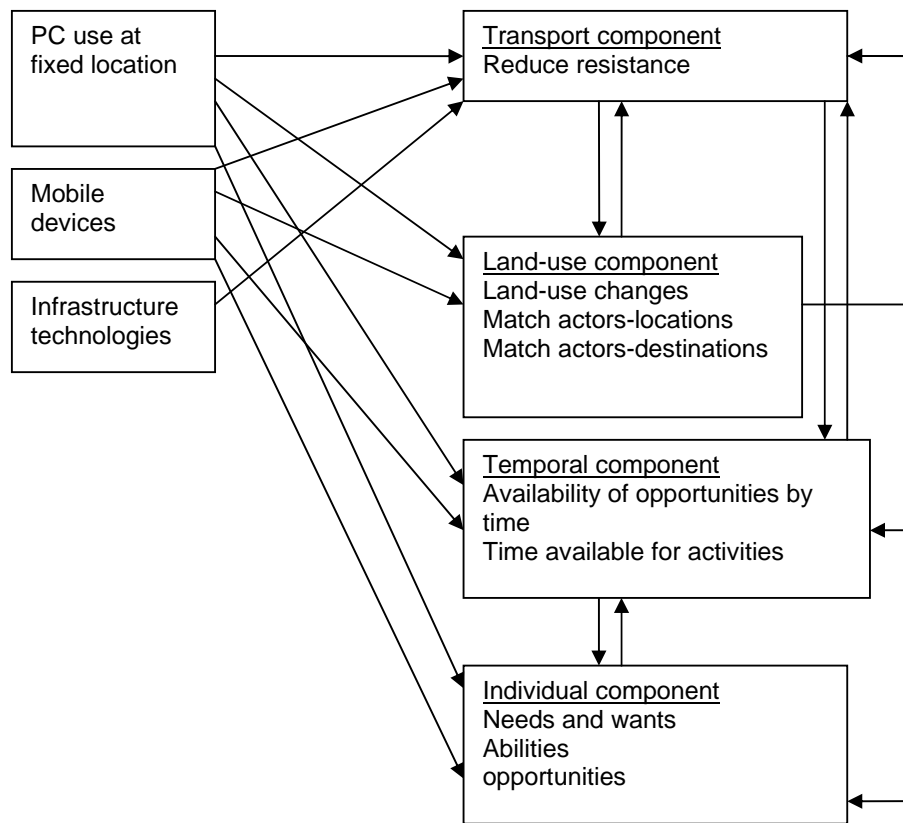Individual component
Needs and wants
Abilities
opportunities

Figure 1 shows PCs at fixed locations and mobile devises have an impact on all four components of accessibility, as explained above. Infrastructure related information provision only directly affects transport resistance. In addition, Figure 1 shows the interactions between the components of accessibility.

6.   Towards a research agenda

We first address some promising areas of research in the area of ICT and travel behaviour, followed by implications for the area of ICTs impact on accessibility. The first area for future research is the broadening of system boundaries. Most research into the area of travel behaviour only considers travel behaviour partially. E.g. only the interaction between e-shopping and shopping trips are considered, or impact of ICT on commuting behaviour. Literature assuming less limiting system boundaries is relatively scarce. But assuming theories on constant travel time budgets (e.g. Mokhtarian and Chen, 2004) it is very likely that substitution or generation effects of ICT for specific trip purposes has implications for travel behaviour for other trips. Because of the broad system boundaries we like the paper of Weltevreden and Rotem-Mindali (2009) who considered the impact e-commerce not only on personal travel, but also on freight travel. In case of business-to-consumers (b2c) e-commerce they conclude that the reduction in personal travel was not fully compensated by the increase in freight transport. In case of consumer-to-consumer (c2c) e-commerce both personal travel and freight transport increased.

Secondly, ICT might lead to making trips at another time of day, or even not at all. ICT is often seen as having the potential to reduce congestion by substituting travel for ICT, commuting being the most frequently used activity category. We would argue that even if ICT would not at all have any impact on congestion levels, ICT can relieve the burden of congestion, by giving people the option to avoid it by travelling at another time, or not at all (but work at home). An extreme situation is that people might intend to go to work, but thanks to ICT they are aware of, for example, a road block leading to extreme congestion, and decide not to travel but work from home. In other words, ICT in this case would prevent them to make a trip for which the disutility of travel is bigger than the utility of the activity (more precisely: performing the activity at that specific place).

Thirdly, we think the interactions between members of a household is important for accessibility in general, and also for the impact of ICT on accessibility. As mentioned above, a person might have temporal constraints that can be solved by other members of the household (see Ettema et al. (2007) for a recent empirical study on this topic). E.g. shopping, picking up children from school, and receiving (b2c-ordered) packages while working can for many persons be substituted between members of a household. And even between persons belonging to the non-household related social contacts, such as neighbours, other parents, the wider family, and friends, substitution of tasks is an option. ICT can improve substitution between persons, e.g. by using mobile phones for calling or SMS, or sending emails. Especially the often rigid person accessibility measures based on time geography might benefit from including such inter-person substitutions. Note that the importance of considering mobility-choices at the level of the household, rather than at the level of the individual, has gained increasing momentum recently (see Timmermans & Zhang (2009) for an editorial of a special issue on the topic). However, as was noted in the context of studies at the still higher level of social networks, it is clear that abandoning the individual as unit of analysis comes at the cost of large increases in complexity.

Fourthly, we consider it likely that within homogeneous groups of people (e.g. based on gender, age, income) self-selection with respect to ICT use in its several forms (see Figure 1) can occur. Residential self-selection is now a generally recognized concept (e.g. Mokhtarian and Cao, 2008; Cao *et al.*, 2009), but as Van Wee (2009) argues, self-selection can occur in several other ways, often – but not exclusively – related to attitudes, in this case towards the use of ICT in its several forms, and next to related behaviour. Insights into self-selection and ICT can for example improve our understanding of the extent to which early adopters' behaviour can be scaled-up to the wider population, as well as our understanding of the true impact of age and gender on ICT use.

A fifth gap in literature is the impact of ICT on the comfort of travelling, as already mentioned in section 4. To the authors' knowledge this is a blind spot in scientific literature, although recently theoretical and empirical efforts have been made to study this potential impact of ICT (Jain & Lyons, 2008; Chorus et al., Forthcoming).

Sixth, a further gap in research to our opinion is the impact of ICT on non-adults. This is firstly important because of the lack in knowledge itself. In addition a life cycle effect related to young people might occur: ICT related impacts on travel and activity behaviour as experienced in the non-adult years might have an impact of these people in their future behaviour.

Finally, up till now we elaborated on research gaps concerning the area of ICT and travel behaviour. We now come to the core of our paper: accessibility. Partly related to the gaps in literature as addressed above, another area of further research relates to developing accessibility measures and indicators integrating physical and ICT accessibility. We think a distinction can be made between (1) measures and indicators for the combined ICT and physical access of opportunities, and (2) measures of access to ICT not having a functional

physical equivalent. The latter category probably can sometimes be ignored in case of travel behaviour related approaches. However, a (small) impact on travel might occur because related activities might compete with others that do need travel. So, an indirect effect of these ICT activities on travel behaviour might occur. A new generation of measures and indicators might include, for example: (1) complementarity versus substitution, (2) multi-tasking while travelling, reducing transport resistance, (3) the positive impact of ICT on accessibility by reducing Generalized Travel Costs, e.g. by making travellers aware of recent changes in the transport system such as new transit alternatives (Chorus et al., In Press), (4) interactions between members of households, or even wider social interactions.

We think within category (1) first of all new indicators could be developed for accessibility itself. In addition, measures for the utility of accessibility could be developed. Note that these indicators are often seen as indicators for accessibility (not the valuation of it). We think a major challenge is to develop activity based models including ICT in its several forms and roles (including its complementarity and substitution role), possibly building on the work of Dong et al. (2006). If such models would be developed, the logsum approach might be an attractive way forward to evaluate the above mentioned utility.

As mentioned in the introduction we exclude goods transport. Though this is outside the scope of this paper, we think a lot of research challenges relate to the impact of ICT on accessibility as far as goods transport is concerned, e.g. access to markets (buying and selling) in general; cultural, legal, and institutional barriers limiting access to markets, and product information. See Denant-Boèmont & Hammiche (Forthcoming) for an early attempt at modelling some of these ICT-related impacts.

7. Conclusions and discussion

Our first conclusion is that much more literature exists on the (potential) impacts of ICT on travel behaviour than on its impact on accessibility. Secondly, we argue ICT potentially has an impact on all four components of the concept of accessibility: (1) the land-use component, (2) the transportation component, (3) the temporal component, and (4) the individual component. We present an overview of challenges in the area of ICTs impact on travel behaviour. Thirdly, there seems to be a major challenge in developing accessibility measures and indicators that include ICT, including those that measure the utility of accessibility. Fourth, in the area of ICTs impact on travel behaviour, many research gaps exist. Examples are the impact of ICT on *overall* activity and trip patterns, impacts of ICT on activities and trips at the household and social network level, ICT as a means to avoid congestion or mitigate its effects, and the role of the phenomenon of self-selection in the context of ICT use. Finally, a challenge for modelling exists: we think a major challenge is to develop models for activities, including ICT-impacts, that combine high levels of behavioural realism with (econometric) tractability. In this regard it should be noted that for practitioner, behaviourally realistic models that are very hard to calibrate or validate, let alone communicate to policy-makers and practitioners, are of limited value.

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