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MODELLING ACCESSIBILITY IN THE AGE OF INFORMATION AND COMMUNICATION TECHNOLOGY

A new approach for accessibility measurement

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ABSTRACT

Our understanding of the possible impact of ICT (information and communication technology) on accessibility suffers from a lack of formal measuring methods. This paper presents and illustrates by means of numerical examples a new model for microscopic accessibility measurement, enabling analysts to measure ICT's effect on accessibility along different dimensions. The proposed model explicitly considers activity-travel constraints (e.g., time and money budget, space-time constraints) and utilities of people's activity-travel pattern in the accessibility measurement, thereby allowing analysts to formally assess ICT's effect on accessibility as a function of its impact on these constraints and utilities.

KEYWORDS

Accessibility, ICT, constrained utility maximization

INTRODUCTION

The primacy of accessibility to human activities and sustainable development is widely acknowledged in many contexts such as economics and sociology (see e.g., Dijst & Kwan, 2005; Iacono, Krizek, & El-Geneidy, 2010; Linneker & Spence, 1992). Furthermore, since decades transport-policy makers are spending great amounts of time and effort in improving accessibility (see e.g., NWO, 2009). Simultaneously, both academics and policy-makers alike have become increasingly interested in the potential of advanced information and communication technologies (ICTs, such as travel information or teleworking technologies) as a policy tool to improve accessibility. Abundant research has identified that ICT may change people's activity-travel patterns, and that as a result of these changes it may also have a substantial impact on the environment, on the spatial distribution of activities and along various other social and economic dimensions (see e.g., Dijst & Kwan, 2005; Farag, 2006; Kenyon & Lyons, 2007; Mokhtarian & Salomon, 1994; van Wee & Chorus, 2009) . It is widely acknowledged that since these aspects are closely related to accessibility, the changes in these aspects caused by ICT ultimately lead to changes in accessibility.

Before policy-makers can safely embrace ICT as a policy tool to improve accessibility, a rigorous quantitative method is needed to measure the extent to which various forms of ICT may affect accessibility. Despite the existence of a multitude of insightful studies, such an integrative measuring method is lacking. So far most developed models to measure accessibility particularly concern with the physical world only, for example dealing with physical notions of distance and spatial relations in geographic space. Such models encounter difficulties when trying to measure accessibility in the hybrid physical-virtual spaces caused by the increased penetration of ICT. Although recent studies have begun to incorporate the use of ICT into accessibility measures (e.g. Dodge, 2000; Kwan & Weber, 2003; Shen, 2000), the models developed in these studies only partly deal with the role of ICT in accessibility. A generic and integrative approach that models both the effect of information and the effect of (tele-)communication (the "I" and the "C" of ICT) on accessibility is still missing.

In view of these issues, we develop a new model for accessibility measurement, enabling analysts to measure ICT's effect on accessibility along different dimensions. The proposed model combines so-called utility-based, people-based and activity-travel-based perspectives, and considers accessibility as the utility of activity-travel patterns of individuals. The model explicitly considers activity-travel constraints and utilities, thereby allowing analysts to quantitatively measure ICT's effect on these aspects and as such on accessibility. In sum, the developed model aims at contributing to the literature by providing an integrative and formal way to measure ICT's effect on accessibility.

MODEL DEVELOPMENT

Accessibility & ICT's potential effects on accessibility: a literature review

Accessibility has been defined in various ways focusing on certain context. Four major types of accessibility measurements have been developed: 1) proximity-based measurements; 2) activity-based measurements; 3) people-based measurements; and 4) utility-based measurements (see, Geurs & van Wee, 2004). In contrast, a small number of accessibility measurements consider ICT's potential effect and they are mostly developed based on the physical measurements. Although accessibility is difficult to be defined as a single universal notion, three perspectives can be conceptualized from these different measurements, namely "activity-travel-based", "people-based" and "utility-based" perspectives.

Many studies identify ICT's potential effects on accessibility in the three aspects (see e.g., Chorus, 2007; Dijst & Kwan, 2005; Farag, 2006; Kenyon & Lyons, 2007; Mokhtarian & Salomon, 1994; van Wee & Chorus, 2009). First, ICT could change people's activity-travel patterns. For example, ICT enables people to do teleactivities (e.g., teleshopping). Second, ICT has effects on the (dis-)utility for people to do activities or travel. ICT may not only change the space-time constructs for people to perform activities, but also reduce the disutility or generate positive utility for travels. Third, there are interactions between ICT and people regarding people's attributes such as attitudes, drives, needs, socio-demographic characteristics. These attributes directly affect people's choice and use of ICT, and, on the other hand, ICT may also change people's attributes.

Towards an integrative accessibility measure

We combine all the three accessibility perspectives in literature and consider a microscopic accessibility measure as the LogSum of the utilities of an individual's scheduled activity-travel patterns (e.g., daily activity-travel pattern of individual) (The LogSum accessibility measure can be referred to Ben-Akiva & Lerman, 1985). The accessibility ACC_n of individual n can be expressed as the maximum expected utility of the activity-travel pattern:

$$ACC_n = E(\max_{S_n \in \bar{S}_n} U_n^S) = E[\max_{S_n \in \bar{S}_n} (V_n^S + \varepsilon_n^S)] = \frac{1}{\mu_n^S} \cdot \ln[\sum_{S_n \in \bar{S}_n} \exp(\mu_n^S \cdot V_n^S)]$$

Where: $\bar{S}_n = \{..., S_n, ...\}$ is the choice set of scheduled activity-travel pattern alternatives S_n; U_n^S is utility of scheduled activity-travel pattern S_n of individual n; V_n^S is deterministic utility of scheduled activity-travel pattern S_n of individual n; ε_n^S is random utility of S_n; μ_n^S is the scale parameter related to ε_n^S. We assume that ε_n is i.i.d. extreme value.

In particular, we will consider the following constraints critical for individuals' activity-travel patterns and accessibility, and literature identify that ICT may have great effect on these constraints: (1) Supply constraints (e.g., network or activity capacity), which also depends on other individuals; (2) Time and money budget constraints; (3) Spatial-temporal constraints (e.g., activity time windows, maximum activity/travel durations); (4) Coupling constraints (e.g. synchronous/asynchronous presence) for individuals to do joint activity-travels.

We use a semi-compensatory utility function to include these constraints as a utility function component and illustrate the utility of activity-travel pattern S_n for individual n as:

$$U_n^S = V_n^S + \Phi_Z(Z_S) + \varepsilon_n^S$$

Where: We use Z_S to illustrate constraint-related attributes (or certain functions of the attributes) of activity-travel pattern alternative S_n for individual n and Φ is the transformation function of constraints into utility function.

Hence, the accessibility ACC_n of individual n, can be expressed as:

$$ACC_n = \frac{1}{\mu_n^S} \cdot \ln[\sum_{S_n \in \bar{S}_n} \exp(\mu_n^S \cdot V_n^S)] = \frac{1}{\mu_n^S} \cdot \ln\{\sum_{S_n \in \bar{S}_n} \exp[\mu_n^S \cdot (V_n^S + \Phi_Z(Z_S))]\}$$

Based on the developed model framework, we can quantitatively analyze different ICT's effects on accessibility via their different resulted changes of V_n^S that may be caused by information provision of ICT (e.g., generate new unknown alternatives; access known alternatives) or the changes of $\Phi_Z(Z_S)$ that may be caused by communication of ICT (e.g., e-activities relax constraints):

$$ICT \rightarrow \Delta ACC_n = ACC_n^{ICT} - ACC_n$$

Where: ACC_n^{ICT} indicates the new accessibility caused by different ICT, ACC_n indicates the accessibility without ICT effect, and Δ indicates the change of accessibility.

NUMERICAL EXAMPLES

A numerical simulation study is carried out in order to clarify some important mechanisms of the developed model framework. The numerical examples of the simulation study indeed provide some first face validity and applicability of the approach to quantitatively measure ICT's effect on activity-travel constraints and utilities, and as such on accessibility.

CONCLUSIONS

This paper presents and illustrates by means of numerical examples a new model for microscopic accessibility measurement. The model combines the three accessibility perspectives (utility-based, people-based and activity-travel-based perspectives) concluded from the literature review and model the accessibility as the utility of activity-travel patterns of individuals. The model explicitly includes activity-travel constraints into the utility maximization function and accessibility, thereby enabling analysts to quantitatively measure ICT's effect on constraints and as such on accessibility. The model also considers the utilities of activity-travel patterns of individuals, thereby providing a way to quantitatively measure ICT's effect on activity-travel patterns and as such on accessibility. The model provides a new approach to measure the extent to which various forms of ICT may affect accessibility along different dimensions.

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