Reconciling user benefit and time-geographical based individual accessibility measures

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1 Background

Accessibility measures has a long tradition in urban and transportation planning. They have been proven useful to address changes in accessibility patterns as a result of large infrastructure investments or land use changes, but also to address social exclusion within an urban area. However, many conventional accessibility measures are limited in scope, such that it is difficult to take into account multi-purpose trips and trip-chaining. The last decade we have seen a new focus in accessibility research to reconcile conventional accessibility measures with the time-geography approach. To explicitly deal with the temporal dimension, Hägerstrand [8], [9] developed time-geography. In a time-geographical framework, both time and space are carefully respected. Many activity-based modelling approaches have been developed in recent years, and with increasing computational power such models are increasingly feasible to operationalize. Thus, in the time-space approach to accessibility, time can explicitly introduced into the inherent static conventional accessibility measures.

From a theoretical point of view, a conventional accessibility measures such as the log sum formula can be closely linked to travel demand. It should also be noted that the logsum formula can also be used directly in a cost-benefit analysis. While this approach is common in environmental economics (McFadden, 1996), it is also used in transportation, in particular in the US, see, e.g., [7], [15] and [19]. See Geurs et al [6] for an overview of the practice of using logsum in applied cost benefit analysis.

To bridge the gap between time-geography and conventional user-based accessibility measures (used in conventional travel demand models) Miller [13] proposed a framework (or research agenda). Building on these ideas, Ettema and Timmermans [3] showed how one can formulate accessibility measures that are directly defined from the theory of scheduling models, as used in transport economics by, e.g., Small [17], Fosgerau and Karlström [5], and Fosgerau and Engelson [4]. Thus, the proposed method proposed by Ettema and Timmermans provides an important link between conventional accessibility measures that are related to user benefit measures, and time geography.

2 The theoretical model

In this paper we further develop the microeconomic framework used in [3] and [11]. The departure point is the static accessibility meausres that are consistent with microeconomic theory within a random utility framework. These measures has many nice properties from both a theoretical and applied point of view. Following [11] we argue that time can easily be introduced into the static framework using a dynamic programming framework, that is in a dynamic discrete choice framework. To put it differently, the Bellman equation (together with a Markov assumption) provides a link between the past, the present and the future, thus introducing time. The static accessibility measure are applied to the present, while state variables represents how the past influenced the present, and thus how the present may influence the future. The Bellman equation thus provides an elegant way to reconcile the well-known conventional accessibility with a time-space perspective.

The first step towards such a model was taken in [11]. In the context of accessibility, Ettema and Timmermans [3] were the first to apply a similar approach, based on the scheduling models of Small [17]. The model by Ettma and Timmermans [3] consider the expected utility given a triplet of destinations and activities (i,j,k), considering two trips and three activities. This is a very useful starting point. However, the model is not closed in the sense that future consequences are exogenous, and not consistently modelled as the consequences due to future decisions in the future etc. In this context, in the present paper we show how applying the Bellman principle we are able to close the model, such that all future possible consequences are, theoretically, taken into account.

To see this, consider the model in [11]. Let s denote state variables, which in our case is taken to be $s = (x, K, F, \delta_{car}, t)$, where x is the geographical location, t is (continuous) clock-time, δ_{car} is a dummy variable defining whether car is available in the mode choice, and K, F describes state variables related to urgency of work-time and shopping. We may think of them as describing the state in the fridge and the flex hour account, respectively. To be able to apply the Bellman principle, we make a Markov assumption, such everything relevant to present is captured in the state variable s.

Given state s, the individual is able to take a number of actions a, which include where to go (or stay), activity, and mode (if travelling). The immediate utility is given by $u(s,a) + \epsilon(s,a)$, where u is the immediate deterministic utility (incurred at present time) when taken action a being at state s, and $\epsilon(s,a)$ is a stocastic term assumed known to the individual and not to the econometrician. The immediate utility $u(s,a)$ may include disutility for travel, utilities for different activities (that may be time-dependent). To close the model we also need to define the environment, describing which states are reached if taken action a in state s. This is described by a probability density (or matrix) p(s'—s,a), the probability of ending up in the new state s', when taken action a while being in state s.

Setting up this dynamic discrete choice model, we are able to close the model by applying the Bellman principle ([16], and [1])

$$V(s) = \max_a u(s,a) + \epsilon(s,a) + \int p(s'|s,a)V(s')ds' \tag{1}$$

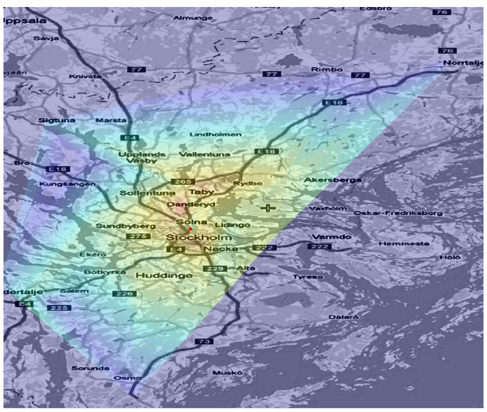
We demonstrate how this can be made computational feasible, and we also take the method to data by estimating the most relevant dimensions of the associated activity-based model. We demonstrate the accessibility measures in the context of gender equity, and travel time variability (which is the focus of Ettma and Timmermans [3]).

3 Results

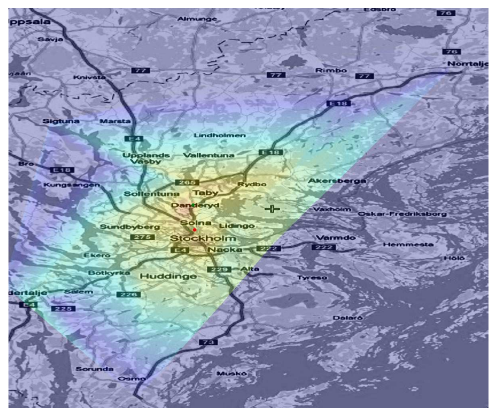
To demonstrate the computational feasibility and some useful properties of the proposed time-space accessibility measures, consider Figures 1 and 2. The value function $V(s)$ are mapped at different time during the morning and afternoon, respectively, keeping all state variables fixed except the location (which is used for mapping).

In short, the maps short the expected value for the rest of life when being at different locations at different times, while maintaining other state variables fixed. The individual that are used as an example here has a time constraint to be at work, in the central Stockholm, at 09:00. The value decreases further away from the workplace, as time approaches 09:00 in the morning. The value will also depend whether the individual has access to car (not shown here). Without car, the value starts to drop earlier in more periferial locations. The figure in the afternoon shows a similar picture, but there is higher values later in the afternoon as the individual (with flexible working hours) are less influenced by work constraints.

There are many other possibilities to explore, and we will focus on gender equality (time window constraints that are different for different individuals in a household), and travel time variability.



(a) 7:30 am



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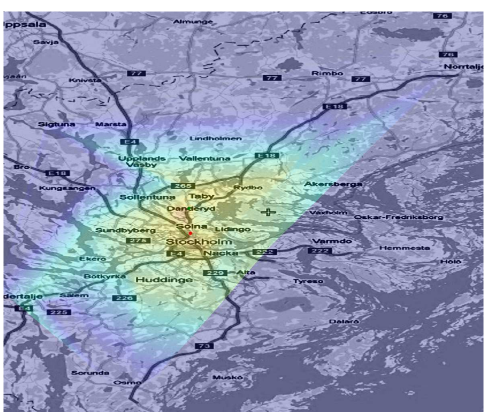

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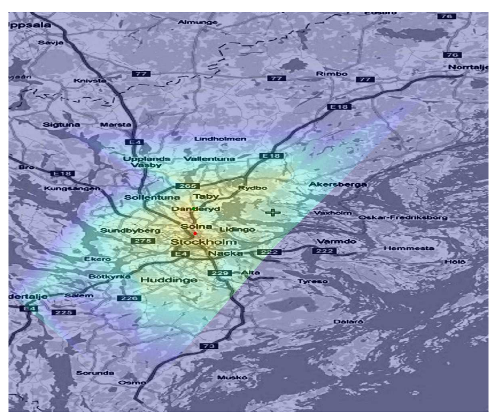
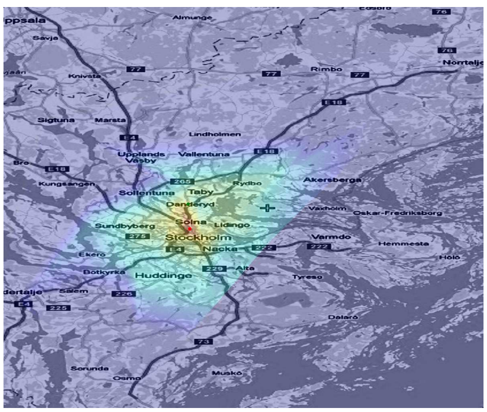
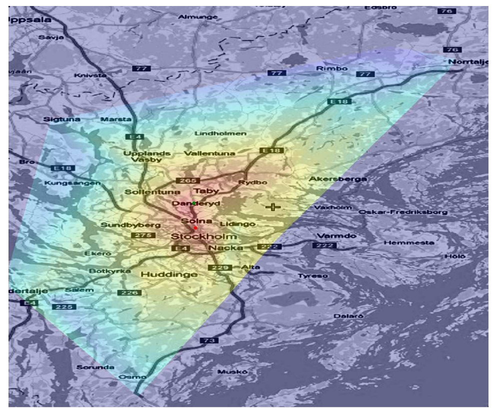


(d) 8:48 am

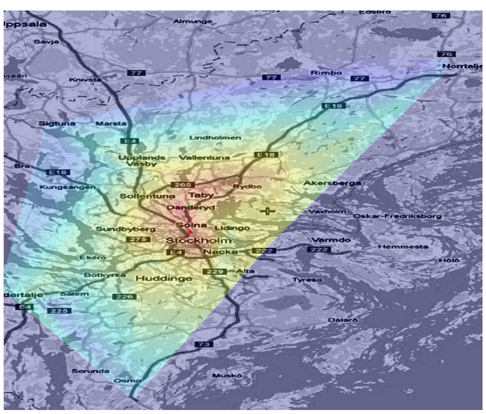
Figure 1: Accessbility during morning hours.



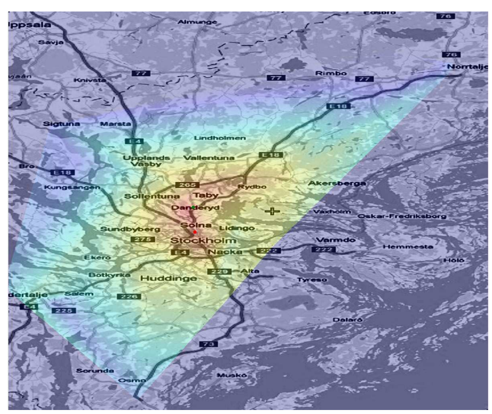
(a) 3:30 pm



(b) 4:00 pm



(c) 4:30 pm



(d) 5:00 pm

Figure 2: Accessibility during afternoon.

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