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A heuristic model of bounded route choice in urban areas

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ABSTRACT

There is substantial evidence to indicate that route choice in urban areas is complex cognitive process, conducted under uncertainty and formed on partial perspectives. Yet, conventional route choice models continue make simplistic assumptions around the nature of human cognitive ability, memory and preference. In this paper, a novel framework for route choice in urban areas is introduced, aiming to more accurately reflect the uncertain, bounded nature of route choice decision making. Two main advances are introduced. The first involves the definition of a hierarchical model of space representing the relationship between urban features and human cognition, combining findings from both the extensive previous literature on spatial cognition and a large route choice dataset. The second advance involves the development of heuristic rules for route choice decisions, building upon the hierarchical model of urban space. The heuristics describe the process by which quick, 'good enough' decisions are made when individuals are faced with uncertainty. This element of the model is once more constructed and parameterised according to findings from prior research and the trends identified within a large routing dataset. The paper outlines the implementation of the framework within a real-world context, validating the results against observed behaviours. Conclusions are offered as to the extension and improvement of this approach, outlining its potential as an alternative to other route choice modelling frameworks.

1. Introduction

Over recent years there has been a growing recognition of the fundamental limitations of traditional route choice modelling. The increasing availability of fine-grained route choice analyses (Nakayama et al., 2001; Papinski et al., 2009), combined with improved analytical capabilities afforded by enhanced computational power, have prompted a reconsideration of the conventions ascribed within Wardrop's Equilibrium (Wardrop, 1952). Wardrop's behavioural assumptions of pure rationality, homogeneity and unlimited knowledge and foresight, inherent within many route choice models, have been questioned by numerous authors (Garling, 1998; Avineri, 2012).

In response, a number of new models have emerged that aim to tackle existing limitations. One strong focus has rested upon the bounded nature of route choice decision making. Bounded rationality has been an important research stream in behavioural economics for some time (Simon, 1957; Sen, 1977), yet the methodologies developed within this field have only recently filtered into route choice modelling. By far the greatest application of behavioural economics within transportation

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behaviour has involved the incorporation of Prospect Theory and Cumulative Prospect Theory (Avineri and Bovy, 2008; Gao et al., 2010; Ben-Elia and Shiftan, 2010; Xu et al., 2011), building on the research of psychologists Daniel Kahneman and Amos Tversky (Kahneman and Tversky, 1979). The Prospect Theory model aims to reflect the non-linear relationship between risk – such as the risk of delay involved in choosing a route – and choice by augmenting the utility of potential alternatives. While these models have bought an enhanced sophistication to the modelling of travel behaviour, an extension into the wider potential offered by behavioural economics has yet to emerge (Avineri, 2012).

An alternative approach to modelling bounded decisions, not previously incorporated within route choice modelling, has been offered in the form of *heuristic decision-making*, a theory put forward by Gerd Gigerenzer and Daniel Goldstein (Gigerenzer and Goldstein, 1996). This theory states that when individuals are required to make decisions under uncertainty, they use simple rules and inferences to determine the relative value of each alternative. The heuristic approach is presented as an alternative to other econometric models of decision-making (including Prospect Theory). As Gigerenzer states: 'Logic and probability are mathematically beautiful and elegant systems. But they do not always describe how actual people ...solve problems' (Gigerenzer, 2008).

Central to the heuristic decision-making framework is the concept that the human cognition contains a 'toolbox' of rule-sets that enable the completion of both simple and complex tasks in a quick and efficient manner (Gigerenzer, 2004). These rulesets, known as heuristics, impose low cognitive computational load and require minimal volumes of information in order to reach a decision (Gigerenzer and Todd, 1999). The heuristics reflect how individuals use cognitive shortcuts to reach intuitively correct decisions.

A number of heuristic frameworks have been outlined and validated (Snook and Cullen, 2006; Pohl, 2006; Goldstein and Gigerenzer, 2002; Brandstatter et al., 2006), each modelling decision making processes through simple rule-based structures. The most widely applied, the Take-The-Best (TTB) heuristic, deals in differentiating between multifaceted alternatives, basing judgement on ranked *cues*, where each cue describes a separate attribute of each alternative. In traversing the set of cues in order, judging between two alternatives, a selection is made at the point of the first significant deviation between the cue values, stopping the decision process and selecting the alternative with the higher cue value. This process is known as 'one reason' decision making, replicates how individuals use cues as indicators of broader utility, when faced with scarce information. This simple inferencing process has been demonstrated to work effectively across a range of scenarios, including investment decisions (Bröder, 2000), court judgements (Dhami, 2004), political election strategies (Graefe and Armstrong, 2012) and medical decisions (Dhami and Harries, 2001). The TTB heuristic has also been demonstrated to match or outperform multiple regression (Czerlinski et al., 1999) and machine learning algorithms (Brighton et al., 2006).

While heuristic decision-making represents an alternative method for choice modelling, research into spatial cognition offers an alternative approach for describing how individuals make choices in urban space. Many conventional route choice models typically represent urban space through the road network and its attributes alone. However, research from neuroscience, cognitive science and behavioural geography indicates that the relationship between individuals and space is much more complex. Instead it has been shown that urban space is mentally encoded and recalled by individuals within a hierarchical structure (Montello, 1998; Tversky, 1993; Golledge et al., 1985; Hirtle and Jonides, 1985), where certain salient features are more strongly recalled by individuals, and so feature centrally within the route choice decision process. In a highly influential work, urban planner Kevin Lynch identified five types of urban feature – paths, nodes, districts, edges and landmarks – as forming the basis of spatial knowledge (Lynch, 1960). The process of the brain recording space as a series of point (O'Keefe and Dostrovsky, 1971; O'Keefe and Nadel, 1978) and region-based (Hafting et al., 2005; Solstad et al., 2008) objects has been furthermore observed in neurological studies, while others have outlined the process by which the brain uses these features during navigation (Wiener and Mallot, 2003; Wiener et al., 2004). A more recent study, using large-scale GPS routing data, has identified non-linear attraction to particular locations on the road network during navigation, resulting in widespread deviation from more optimal alternative routes (Manley et al., 2015). Despite the evidence supporting the importance of the spatial hierarchy in navigation decision-making, application of this model has not been widely applied within transportation studies. While a few route choice models have incorporated landmarks and anchor points as a potential influence on navigation (Prato et al., 2012; Kaplan and Prato, 2012; Arentze et al. 2014; Chown et al., 1995), the modelling of route choice within a complete hierarchical representation of space has not yet been undertaken.

This paper draws together research into heuristic decision making and the cognition of space in introducing a novel approach to modelling route choice decision making. The route choice framework encodes choices as sets of simple heuristics, based on a hierarchical spatial structure corresponding with the construction of cognitive spatial knowledge. The heuristic modelling approach represents an alternative methodology to the utility maximising paradigm currently dominant in route choice modelling. The use of a hierarchical representation of space recognises that navigation decisions in urban areas may be based on an array of spatial features, rather than purely road connectivity and route conditions. While this paper will introduce one configuration and implementation of this new framework for route choice modelling, it is hoped that the framework will serve as an alternative methodology for future route choice modelling, within wider urban transportation modelling stacks where individual-level behaviours are represented (e.g. activity-based, agent-based models).

To achieve these objectives, this paper integrates previous findings within the literature with observations drawn from a large dataset of route traces, leading to the development of a new route choice modelling framework. The paper presents the implementation of the model within a real-world environment. The paper is structured as follows. The next section describes the route dataset that will support the development of the model framework. The following third section outlines the development of the hierarchical model of urban space across which route choices will be made. The model is based on the