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Use of an agent-based model to explore urban transitions in commuter cycling

SMA Abbas
University of Cambridge
aa797@medschl.cam.ac.uk

Rachel Aldred
University of Westminster
r.aldred@westminster.ac.uk

Zaid Chalabi
London School of Hygiene and Tropical Medicine
zaid.chalabi@lshtm.ac.uk

James Woodcock
University of Cambridge
jw745@medschl.cam.ac.uk

***Abstract*— Encouraging a cycling culture while reducing car usage can lead to substantial health and environmental benefits. In this exploratory work, we use an agent-based model of commuter cycling focusing on the emergence of social norms due to interactions between agents and their environment (including their social networks). The overall goal is to develop an understanding of change and continuity in cycle commuting, and how this is shaped by dynamic relationships between social expectations and individual attributes. Initial characteristics of agents and the distribution of cycling in the population come from the Census and secondary quantitative data. The theoretical basis of our work comes from qualitative studies on cycling and from 'Theories of Practice', which see practices as enrolling individuals, depending on whether they have the material and cultural resources required to participate. Thus, rather than treating humans as rational individuals who, for example, follow the precepts of utility maximization, we explore how changes in norms surrounding cycling practices (such as social expectations around clothing and accessories) shape uptake, and how uptake then affects social norms relating to cycling., We test policies for increasing cycling usage based on provision of cycling stuff and improvements to the environment.**

I. Introduction

In this project we have developed an agent based model (ABM) to help understand how the transition to high cycle commuting cultures could be achieved. Mass cycling has the potential to achieve substantial health and environmental benefits [1]. For this we have drawn on largely qualitative research on cycling in England and been informed theoretically by insights from theories of practice. Theories of practice offer a distinctive perspective on agent behaviour [2]–[4]. Within transport, agents have typically been modelled as utility maximizing actors with static preferences for transport modes. Other approaches, focusing on potential for behaviour change, seek to identify psychological states associated with shifts from intention to action.

This paper's alternative approach is drawn from sociology. Priority here is given to the lived occurrence of the behaviour and the different elements that constitute it in different environments. Social norms are seen as interacting with individual characteristics. Core concepts – meanings, abilities (skills) and stuff (materials) – come from practice theories. All three concepts are defined as having both a social and an individual dimension.

In our case, the social dimension refers to shared perceptions about the cycling context, in relation to meanings, abilities, and stuff needed. For example, where cycling is perceived as very dangerous, it may also be widely believed that only very able and fit people, possessing large amounts of cycling equipment, can cycle. Conversely, where cycling is seen as a safe, everyday activity not requiring specialist clothing, it may also be seen as something that many people of varying abilities may wish to be associated with. Beliefs within cycling contexts will vary along a distribution, but, we believe, they can still be characterised and contrasted. In this version of the model we simplified complex relationships by (a) omitting 'abilities', so focusing only on stuff and meanings and (b) concentrating on what evidence suggests to be the most important meaning in the UK: danger.

The individual dimension refers to (i) the extent to which an agent wishes to be (dis-) associated with specific meanings (in the case of danger this can be seen as the level of tolerance for danger) and (ii) the level of cycling-related stuff owned by the agent. Individual danger tolerance is simplified as only changing with age while stuff is dynamic: changing as people gain or lose cycling-related stuff. The social dimensions of meaning will shift in relation to the changing individual characteristics of people who cycle (agents update their knowledge of the cultural context based on what they see others doing). This approach foregrounds the relationships between social norms surrounding cycling and the individual characteristics or preferences corresponding to those norms. It enables us to examine how both social norms and individual attributes might shift, and the relation of this to changes in cycling practices.

II. Model Description

Purpose: The purpose of this model is to understand the practice of commuter cycling and test interventions which may lead to transitions. Cycling practices are conceptualized as the outcome of social norms and expectations, individual attributes, and social interactions and observations.

Initializing: The number of agents is fixed in the simulation and does not change with time, although individual agents leave (retire) and are replaced. Demographic characteristics and initial distributions of predispositions towards cycling are informed by the

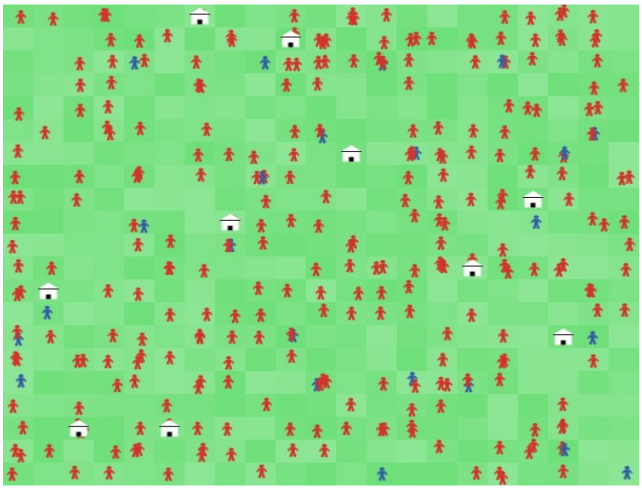

Figure 1 - Model Environment

Census and other secondary data sources. The cycling context is set at initialisation from one of the three cultures: low, emerging and established. All three cultures represent various contexts (cities and within them workplaces and neighborhoods) in the UK based on the population, perception and infrastructure for cyclists. These are based on our previous work [5], and are defined by the levels and types of cycling practices that are dominant, which affects the extent to which such practices are exclusive or inclusive, and who is included or excluded. The social network covering households, workplaces, neighbourhood, commute zone is initialized on a random basis, but the topology of the network is made as a power-law outlook for degree distribution. This network is dynamic in nature to mimic real life.

The social networks (composed of family, friends, neighbours and work colleagues) and people observed while commuting affect understanding of cycling practices and the requisites for and barriers to participating in the practice. Each agent represents an individual in our model, with heterogeneous characteristics and orientation towards local cycling practices. There are three categories of links between people: core ties, strong ties and weak ties. Literature on social networks suggests that number of ties when plotted on a log-log scale against the number of people, is linear. In other words, the number of ties follows a power-law degree distribution [6]. For each agent, there are five core social links which are biased toward one's neighbours and work colleagues. On top of that, for weak and strong ties, we use the *Social Circle* algorithm [7] to develop a scale-free social network – a few people have a lot of links, while the majority have a fewer links. We constrained the overall network to have a higher clustering coefficient compared with a random network with the same density. Table 1 shows the overall initialization process.

Figure 1 shows the main environment of the ABM. The colour of the individual agents represents their cycling status (red for non-cyclist and blue for cyclist). The workplace agents are represented by small houses, and the colour of the patch represents the quality of the cycling environment

Set the dimension of the square grid (20×20)
Divide the agents into two types: A (people) and B (workplace)
Assign fixed number (usually 30) of agents A in each workplace B.
Divide cycling cultures into three types: low-cycling culture, emerging cycling culture, and established cycling culture.
Based on the culture, define the initial percentage of cyclists (2 for low; 8 for medium; and 30 for high cycling culture)
Set (3-5) social links for each agent – known as core links. On top of that, develop strong and weak ties based on power-law outlook.
Initialize meaning (personal danger & cycling danger), stuff (needed, owned, and used) according to their initial distribution.

Table 1- Overall Initiation Process

Culture specific danger variables:

Figure 2 shows for each of the three cultures the initial distribution of personal danger based on the findings of qualitative studies [5], [8]. The red curve represents low cycling culture where the majority of the people have a much higher association of cycling with danger. In high cycling culture it is completely opposite – there is a very low association with danger, whereas in the emerging cycling context, the cycling danger is symmetrically distributed.

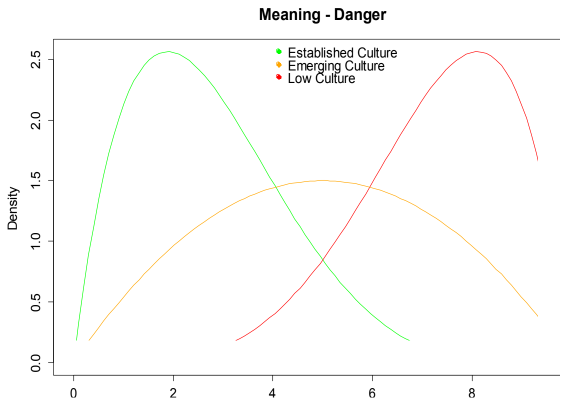

Figure 2 - Cycling Danger in Different Cultures. The X axis shows the strength each culture gives to cycling danger. It ranges from 0 to 10, where low value represents low, and high value represents high strength. The Y-axis shows the population density.

We have also incorporated incidents into our model which represent any kind of negative experience while cycling. These include, for example, abuse from motorists or pedestrians and near misses [9] but do not cover much rarer serious injuries. The risk of incidents is assumed to be related to the quality of the environment.

Model Run: After initialization, each agent, depending on his/her social network and cycling history, either has or has not the resources to engage in a local cycling practice. Each time step covers a week). At each time step, changes in the observable characteristics of the agents, such as their cycling stuff, are recorded. Changes in the nature and composition of cycling practices in areas of the abstract geography defined by a matrix of square grids are determined.

Influence:

It is assumed that each agent is influenced by four sets of agents:

1. Those living in the agent's home zone
2. Those working in the agent's workplace zone
3. Those in the agent's social network
4. Those who traverse the agent's commuting zone

The four types of network differentially enable two types of social influence: social observation (SO), and social interaction (SI). The first three sets of agents have both types of influence (SO, SI) whereas as the fourth set agents has only the second type (SO). SO describes when an agent observes other agents cycling (for example, in the local neighbourhood) whereas SI describes when an agent has a social interaction related to cycling with another agent (for example, a work colleague). The probability of a social interaction is influences by the strength of social ties.

Dynamics:

Stuff Needed: Based on observing and interacting with others, each agent may change their perception of the stuff they think is required for cycling (e.g. helmets, bike locks). We have chosen to focus on safety equipment as this is most associated with the danger meaning.

Stuff Owned: Each agent may change the cycling stuff they own, unilaterally, or through social interactions (by borrowing or donating). Stuff is assumed to be randomly and slowly lost over time.

Stuff Observed: Each cyclist observes other cyclists which s/he sees in her/his commute path, and then adjusts their perception of stuff (needed) accordingly.

Meanings: Taken from the qualitative literature, we identified seven meanings potentially associated with cycling; (1) danger, (2) fitness/health, (3) poverty, (4) affluence, (5) environmentalism, (6) fashion, and (7) "suitable for my demographics". In this model, however, we have focused on the meaning of danger as this meaning is widespread and strongly shapes currents patterns on cycling in England [10]. The degree to which cycling is associated with danger is updated dynamically based on observations of, and interactions with, other agents.

We assumed a linear relationship of cycling danger with stuff-owned. The more safety stuff someone owns, the more likely they will associate cycling with danger. At every simulation step, the stuff owned will (fractionally) move cycling danger towards this linear relationship.

Enrolment into cycling is influenced by (a) whether the stuff possessed by the agent equal or exceed the stuff s/he thinks s/he needs, (b) whether s/he wishes to be associated with those meanings s/he associates with cycling, and (c) their cycling experience in the past year.

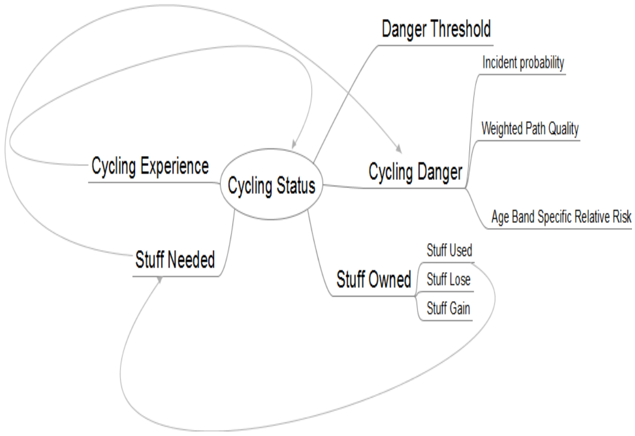

Figure 3 - Overall Mechanism

Figure 3 displays how attributes about stuff and danger towards cycling, would help determine the cycling status of a commuter. Overall enrolment in cycling practice depends on: cycling experience (experience of the past year), stuff needed, stuff used, cycling danger, cycling danger threshold. If an agent has sufficient stuff, and also his/her cycling danger is greater than his/her danger threshold, then s/he becomes a cyclist. Figure 3 also specifies how an incident affects cycling danger. Incidents occur probabilistically based on the environment a cyclist is exposed to in his/her path and their age specific relative risk. If an incident happens, it negatively changes the perception of cycling danger. This change in perception is also propagated through the social network. Unlike other attributes in this figure, the stuff needed is an observational variable based on the other cyclists one observes in his/her commute path. Based on the principle of homophily, people are more influenced by people of their own gender, age and socio-economic status.

We have implemented two potential strategies to increase cycling, (i) improvement in the cycling infrastructure, and (ii) workplace policies to provide safety stuff to employees.

III. Results

We have drawn results from our model focussing on two aspects. The first aspect is the changing trend of the proportion of cyclists over time. Figure 4 shows a sample of 10 stochastic trajectories of cycling trend in low cycling culture over a simulation period of 10 years (with the same fixed settings). We have not set a random seed with a fixed value in the random number generator to exhibit the different trajectories. The overall average remains approximately the same as the initial population of cyclists (2% versus 2.1%).

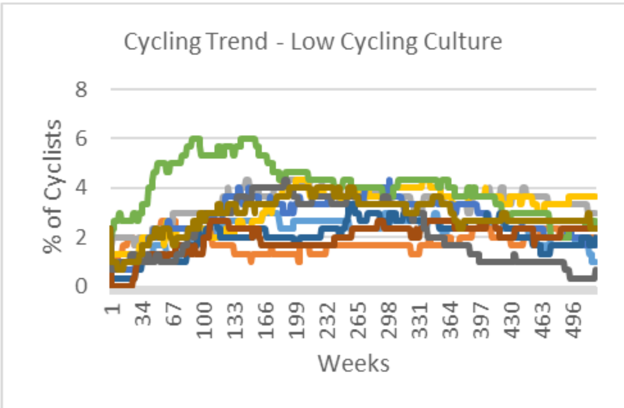

Figure 4 - Cycling Trend for Low Cycling Culture

Similar results have been drawn for emerging and established cycling cultures in Figure 5 and Figure 6 respectively. As in the case of low cycling culture, each result comprises 10 trajectories. In the emerging culture, the percentage of cycling increases in the first year and then remains stable for the next two years. After that it starts declining – and ends at 7.8%. However, in the established culture, the cycling rate remains stable for the whole simulation period. In this case, the overall average percentage reduces from 30% to 27.9%.

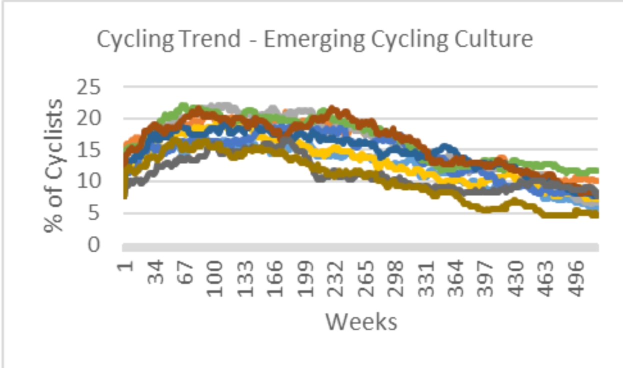

Figure 5 - Cycling Trend for Emerging Cycling Culture

The second aspect we focussed on is the evolution of cycling practices over time. We investigated practices by examining whether meanings and stuff cluster and if so whether these clusters relate to demographic and workplace characteristics. For illustrative purposes, we show the results of one of the cycling cultures – the low cycling culture. Figure 7 shows that nine clusters have been identified based on the initial group classification. The stuff owned goes hand in hand with cycling danger; both are low or both are high.

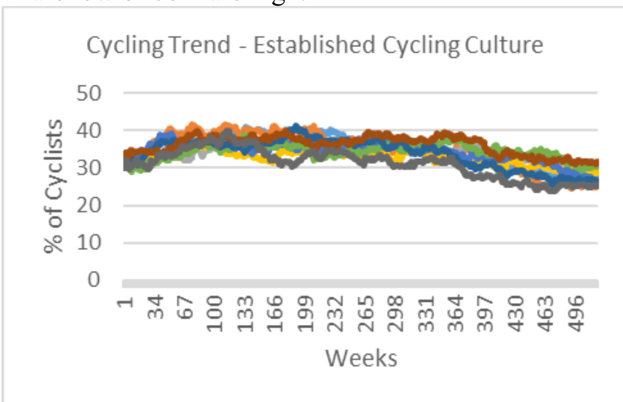

Figure 6 - Cycling Trend for Established Cycling Culture

Figure 8 shows the changes of practices at the end of the simulation period (after 10 years). The number of clusters has been reduced to five. With the perception of danger associated with culture increasing over time, the stuff owned has also increased. Several diverse cycling practices have emerged. In the figure below, for instance, the red boxes represent one cycling practice which revolves around low to medium levels of stuff owned with that of medium level of association with cycling danger.

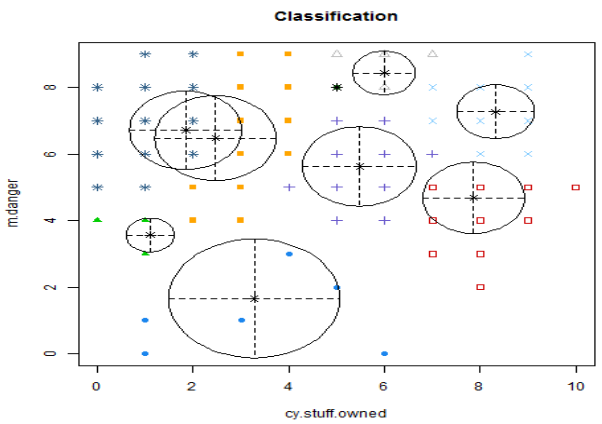

Figure 7- Cycling Practices clustered by Stuff Owned and Cycling Danger at Week 0. The X-axis shows how much cycling stuff people own (low value represents low stuff, whereas high value shows more stuff). The y-axis show cycling danger (low value represents lower cycling danger)

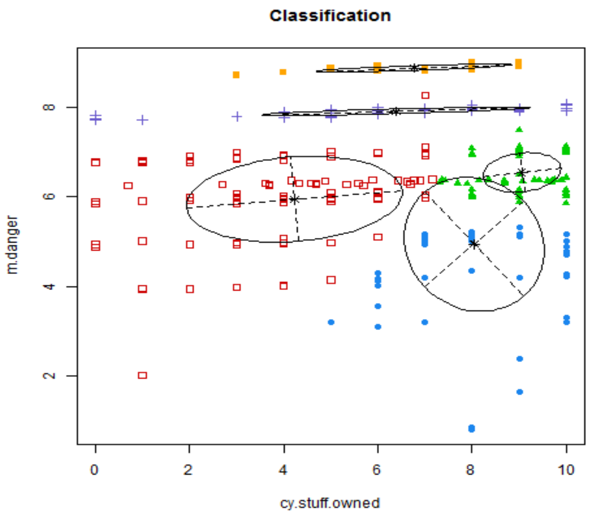

Figure 8 - Cycling Practices at the end (year 10)

IV. Conclusion and Future Work

In this paper we have presented a model of uptake of cycling to work which is inspired by the theories of practices. The enrolment in the cycling practices is an outcome based on both individualistic perceptions (meanings) and assets (stuff), as well as social interaction and observations (of both environment and other people). We have employed cluster analysis to identify various cycling practices and their evolution over time, based on meaning and stuff. Ongoing analyses of three qualitative datasets will help us determine the goodness-of-fit of these clusters. We will investigate how the clusters evolve over time and whether they exhibit sudden transitions which represent discontinuities or phase shifts from one type of behaviour to another. In addition, we will investigate how to quantify the uncertainty in the clusters resulting from propagating upstream uncertainties (e.g. uncertainties in the behaviour rules).

Model outputs are in turn being analysed qualitatively, with analysis both of sample cluster characteristics in each context and of sample individual trajectories from all clusters and contexts. This will then be compared with research findings about such cycling cultures, to establish the plausibility of the individuals and clusters being simulated. Similarly, narrative analysis of model outputs relating to our intervention scenarios will be studied for plausibility in relation to evidence around the two types of intervention being modelled.

Acknowledgment

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