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Testing self-perception theory with agent-based simulation

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Abstract

Conventional wisdom is that a person's attitude towards an issue dictates their behaviour. In contrast, self-perception theory accounts for how a person forms their attitude. In the context of this paper, the theory asserts that a person can, in the absence of prior experience, establish an attitude towards cycling based on observing their own, hopefully, positive experience. The adaptive agent-based model, MATSim, allows one to test the self-perception theory. The case study in Cape Town, South Africa, demonstrates that as much as 7.8% of people introduced to cycling will experience it as positive, opening the door for adoption.

Keywords: self-perception theory; MATSim; cycling; starter city; agent-based simulation

1. Introduction

As climate change pressure increases in tandem with growing urban environments, authorities, practitioners and researchers aim to drastically reduce the citizens' mobility carbon footprint. Ballo et al. [1] argue in their thought-provoking think piece that all the recent developments, like autonomous vehicles, electrification of fleets, and shared mobility, amongst others, are incremental improvements that will not bring us close to carbon neutrality within the stated time frame. Instead, we need more drastic behavioural changes. Cycling offers such an opportunity, but the uptake is (too) slow. Why, precisely, given all the health and cost-related benefits cycling offers?

The literature argues that attitude towards and perception of cycling frequently inhibit people's mode choice towards the healthier alternative. Self-perception theory, popularised by Bem [2], posits that people change their perceptions and attitudes towards a subject from observations about their behaviours and experiences of that subject. For instance, a positive experience while cycling would foster a positive attitude towards cycling, where it may have been

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neutral or negative before. Such a positive attitude is then likely to result in a behaviour change, i.e. a shift to cycling. But how do we get people to *try it once* to gain a positive experience?

This paper contributes to the body of knowledge by using advances in agent-based transport modelling to demonstrate the use of self-perception theory to inform policy. Agent-based modelling allows for interventions where individuals can experience a mode and adapt behaviour if the result is positive—in the case study of Cape Town, South Africa, applying the self-perception theory resulted in a significantly improved generalised utility across the population.

The paper is structured as follows. Section 2 briefly provides an overview of cycling starter cities and the application of self-perception theory. Section 3 introduces the model and case study for Cape Town, with Section 4 discussing the results. Section 5 concludes the paper and points to future work.

2. Literature

Silva et al. [9] describe cities with negligible utility cycling that have aspirations to grow the mode to significant levels as *starter cycling cities*. Starter cycling cities with a car-dominated transportation system tend to have lower densities and a sprawling urban form. Faced with land use challenges and their resulting impact on travel distances, authorities in the starter cycling cities need help knowing whether interventions are warranted and, if so, which intervention to prioritise and where to focus those.

The challenge in a starter cycling city is that an attractive environment for cycling still needs to be created to invite individuals to test this subject (cycling). Asking people to try cycling under unfavourable prevailing conditions is likely to create or reinforce negative attitudes towards cycling. However, planners could use agent-based modelling to emulate a conducive environment where the model builder invites individuals (agents in the model) to experience bicycle performance for their most recent travel plans.

Macal [8] acknowledges and explains that agent-based models can mean different things to different audiences and provides four definitions. In its most basic form, an agent-based model can reflect that the model presents and handles objects (or agents) *individually*, and the agents can have diverse characteristics. The second definition is that the model is *autonomous*, with agents having internal behaviour, sensing the environment and responding accordingly. The third definition caters to *interactive* models where autonomous agents interact with other agents and their environment. Finally, an *adaptive* model allows individual, autonomous agents to interact while adapting and learning as they progress. The Multi-Agent Transport Simulator (MATSim) of Horni et al. [6] is an adaptive agent-based model that caters explicitly to mobility and accessibility modelling. Agents each have a sequence of activities connected by mode-specific trips that describe their daily activities, called plans. Each agent has a configurable number of plans they can keep in memory. Agents score their executed intentions at the end of each day in terms of the experienced generalised utility: positive utility for participating in value-adding activities and negative utility for waiting, travelling and penalties associated with missed opportunities. The coevolutionary mechanisms ensure that plans that score well survive while unattractive plans do not. Agents can adjust their plans in subsequent iterations to account for changes in travel behaviour like departure time, route, and mode choice, amongst others. Alternatively, agents can demonstrate habitual behaviour by picking one of the plans from memory.

The model's value is to simulate for whom cycling also holds a travel time advantage above their existing modes. Self-perception theory [2] then holds concerning one parameter, a positive travel time experience, likely to foster a more positive attitude towards cycling for some. But since self-perception theory is not conventional and goes against the *attitude-drives-behaviour* norm, there is not much literature on the topic, especially concerning transport. van Wee et al. [10] briefly introduce the concept but only a single contribution they reviewed implicitly catered for the theory. Woosnam et al. [11] explain how people's travel history affects and shapes their attitudes toward tourism development.

Where the number of persons that may change their behaviour towards choosing cycling is significant, the policy decision to invest in creating a conducive environment becomes attractive and defendable. City authorities can then target interventions to address other parameters influencing how these individuals experience cycling when invited in real life.

3. Model

This section describes the baseline model representing the status quote and the cycling scenario that illustrates the self-perception theory experiment. Both benefit from *OpenStreetMap* for the road network.

3.1. Baseline scenario

This paper benefits from Joubert [7] for the synthetic population of agents, which is accurate in its individual and household composition. The public data for the City of Cape Town's functional area represents its 2021 population. We need to provide travel demand for each individual, and we do that courtesy of the City of Cape Town [4] household travel diary. Picking a daily travel plan—the sequence of activity types and connecting mode-specific trips—consider a demographic signature matching between the synthetic population and the travel diary's individuals.

We adjust the activity locations of the sampled travel plan to account for the person's home location, travel distances between primary activities, and an ellipsoidal envelope between primary activities for the secondary activities. We achieve finding locations for primary activities other than home by performing a doubly constrained matrix balancing of origins and destinations.

The resulting population with travel demand is the input into a MATSim run for 200 iterations, allowing agents to replan by adapting their departure times and altering their routes. Those agents that do not travel by private car, either driver or passenger, teleport between activities, implying that their detailed movement is not accounted for on the road network in the mobility simulation. The teleporting travel time between activities is mode-specific and takes access and egress walk time into account, as well as in-vehicle time. The mode-specific teleportation alteration is necessary to ensure the travel time for cycling is attractive compared to, for example, bus rapid transit, but only over short distances. Over longer distances, bus rapid transit's fast in-vehicle speed overcomes its longer access time and outperforms cycling.

3.2. Cycling scenario

Following the coevolutionary and adaptive mechanisms in MATSim, the output of the base scenario sees each agent having a set of five surviving plans. Like the approach followed by Hitge and Joubert [5], this paper calculates a probability for each agent that represents its potential to consider cycling. The calculation accounts for age, gender, household composition (size) to which the agent belongs, dwelling type (formal or informal), and the combined household income.

For each of the 100 synthetic populations, we calculate the cycling potential for each person and perform a weighted sampling based on the estimated value. Sampled individuals are tagged accordingly with a unique attribute. From the central limit theorem, the distribution of the number of potential cyclists follows a normal distribution. We pick one of the populations whose sampled cyclists are close to the distribution's median.

We give each tagged individual from this population a bicycle in the spirit of the self-perception theory. In the data, we implement this as follows. We randomly sample one of the agent's travel plans from its memory. For each trip in the plan, we change the mode to cycling. The brute force mode adjustment is analogous to giving the person a bicycle and saying: *"use the bike for one day without changing any of your activities. Just try it!"*. The new cycling plan replaces the agent's worst plan in their memory, and we set it as the chosen plan in the subsequent simulation run. Each agent with a modified cycling plan will, therefore, at least try it once.

4. Results and discussion

We execute MATSim again for 200 iterations, using the cycling scenario as input. Over the simulation runs, we can track the generalised utility of each agent's best, worst and executed plan in their memory during each iteration. Over the entire population, we can then report the average of these best, worst and executed plans. And this is visualised in Figure 1.

The baseline scenario, presented in grey, represents the first 200 iterations, and the reader can observe how the scores converge as the simulation settles into a relaxed state. After 160 iterations (80%), the simulation machinery

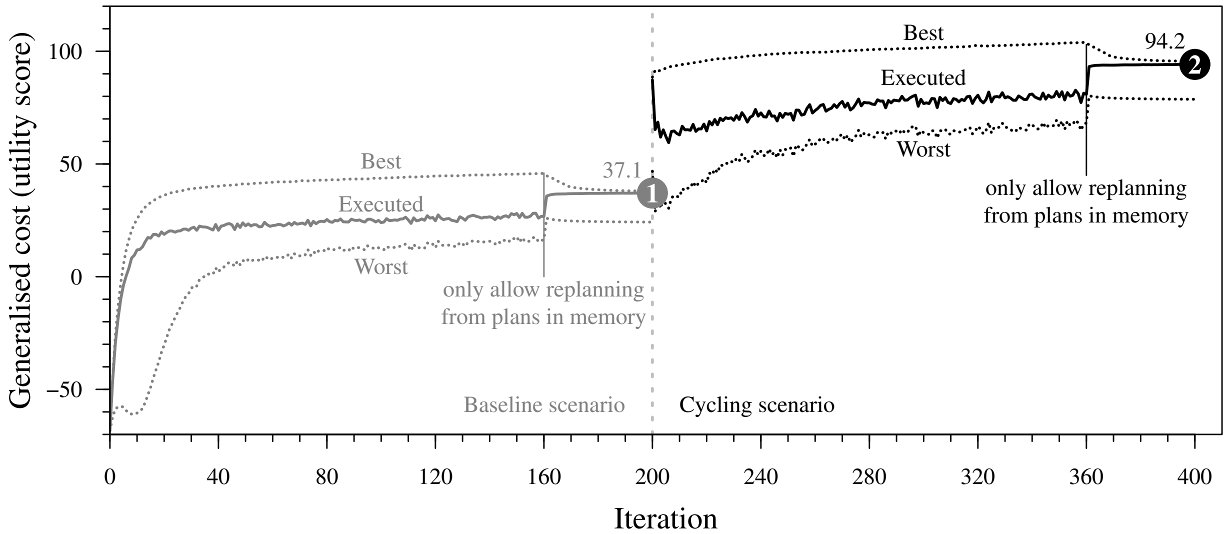

Fig. 1. Conversion of the two scenarios. The baseline scenario is depicted on the left half in grey, from iteration 0 to 200, while the cycling scenario is depicted on the right half in black, from iteration 200 to 400.

terminates the agents' ability to change their departure time or routes, only allowing them to pick from their memory of prior plans. The baseline scenario converges to a generalised utility of 37.1 units.

Similarly, the cycling scenario converges, albeit slower. We attribute this to the fact that only 15% of the agents received a cycling plan, leaving most other agents only to respond and adapt to the road capacity released by new cyclists. Here, too, innovation is switched after 160 iterations after the simulation started, thus at iteration 360. The cycling scenario converges to a generalised utility for the mean executed plans across the population of no less than 94.2 units. That is a remarkable 253% increase over the baseline scenario.

The cycling scenario started with approximately 12.5% of the agents having a newly allotted cycling plan. Each of these agents executed their cycling plan in the first iteration of this scenario. Some will experience the cycling plan as horrible and score it very severely. For these agents, the other plans in memory might have higher generalised utility and may be chosen and altered in future iterations. The future choice is because the more attractive a plan is perceived, based on experience, the higher the probability the agent will pick it in a future iteration. Cycling, for these agents, will not survive.

Conversely, some agents will execute their new cycling plan and find that it provides them more utility than their initial plans in memory. In this case, cycling's initial mode share of 12.5% reduces to a still respectable 7.8%, quite in line with the City of Cape Town [3] ambitions.

5. Conclusion

This paper demonstrates that the agent-based approach of MATSim allows the model builder to test the self-perception theory. The model enables one to test scenarios where individuals receive a bicycle based on their likelihood to adopt cycling in the first place. But person-specific circumstances, like travel distances, may prove cycling to be or remain unattractive. For others, it may lead to identifying and confronting one's (initially negative) attitude towards cycling because the actual experience yields benefit.

Analysing a disaggregate, person-level model's rich results can support authorities' decision-making. Interventions to promote cycling can now be more targeted. Where are the individuals living for whom cycling survived? What nodes are attractive destinations? What corridors can best benefit from infrastructure changes conducive to cycling?

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