AGENT-BASED MODELLING OF A SOCIAL DILEMMA IN MODE CHOICE BASED ON TRAVELERS’ EXPECTATIONS AND SOCIAL LEARNING MECHANISMS

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Abstract. This study attempts to apply an agent-based approach to modelling travel behaviour. A social dilemma situation of travel mode choice is modelled and viewed as a complex system by considering psychological and sociological aspects, which are represented by individuals’ expectations and social learning mechanisms. We apply an imitation game in order to evolve the decision making rules of each traveller. The study reveals some informed insights for resolving the social dilemma, such as the conditions that make cooperation as a possible outcome. Some behaviour and policy implications are also discussed in this paper.

1. Introduction

Many agent-based models in transport have focused on travel route choice, with emphasis on day-to-day simulations. Travellers were modelled to have bounded rationality, limited information and capable to do cognitive learning [7]. A decision-making framework named belief-desire-intention (BDI) has been developed and used for modelling route choice and departure time choice behaviour [8], as well as a study to investigate the influence of real-time information on route choice behaviour [2]. In travel mode choice, an insightful theoretical work has been done by Kitamura et al [6], utilizing a simple bi-modal transport system and cellular automata. In our previous work, we have also tried to develop an agent-based model on mode choice behaviour, utilizing finite-state machines as decision rules [9]. These studies in route choice and mode choice, as well as others in related transport field, have shown that agent-based approaches are very promising for transport modelling, since they offer many potential benefits that may not be gained in conventional approach.

The decision to commute by car or public transport not only has an impact on the

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individual traveller, but also on other travellers. This particular type of interdependence with conflicting individual and collective interests can be framed as a social dilemma. Based on two basic properties of social dilemma [1], the dilemma in travel mode choice can be represented in a very simple mode choice situation that comprises car and bus as the only modes of transport in a shared highway space [6]. Resolving the dilemma is not easy since there is a temptation to be selfish and maximize personal benefit. In general, the ways of resolving the dilemma can be categorized into two kinds of approach: (a) structural approach, which includes interventions that change the structure of interdependence and effectively eliminate the dilemma. For example: changing payoff structure (e.g. congestion charging), reward-punishment (e.g. incentives for public transport users), or situational change (e.g. residential relocation); (b) individual-psychological approach, which includes interventions aimed at influencing attitudes and beliefs that may guide people’s cooperative and non-cooperative behaviours. For example: promoting travel awareness and workplace/school travel plans. Some factors that are considered in the second approach are: altruism, morality, beliefs and expectations, normative concerns, consciences, and social norms. In this study, we are particularly interested in resolving the dilemma using the latter approach by considering beliefs and expectation as influential factors.

The decision of an individual on whether or not to contribute to the collective good depends not only on the past but also on their expectations as to how their actions will affect those of others [4]. Expectations rest on two main principles. Firstly, individuals believe that the influence of their actions decreases with the size of group. This principle can be simply given a meaning that “the bigger the group size, the less a single individual action will affect group behaviour”. Secondly, individuals believe that their actions influence others to a degree that depends on how many individuals cooperate. In other words, there exists a “critical mass” between cooperation and non-cooperation. Over the critical mass the more people cooperate, the more this action will influence the others to cooperate. Reversely, below the critical mass the more people not cooperating, the more others will be influenced not to cooperate. There are two classes of expectations that most represent human expectations, the bandwagon expectations and the opportunistic expectations [5].

On making a decision, individuals utilize social learning, instead of individual learning. This kind of learning mechanism enable people to short-cut individual learning and leapfrog to adaptive behaviours by learning from others. This kind of learning is likely to occur from the interactions between members of a group, or in wider context a society.

There are several kinds of social learning mechanism [3]: conformist transmission, payoff-biased transmission, self-similarity transmission, punishment of norm violators and normative transmissions. In this study, we consider only the first two learning mechanisms.

2. Objectives of study

This study aims to provide a model of travel mode choice in a bi-modal (car and bus) choice situation utilizing the agent-based approach in order to understand behavioural process of travellers on choosing travel mode. The role of beliefs and expectations on travel mode decision making will be investigated, as well as the influence of social learning as the way of spreading behaviour. Each traveller, modelled as an agent, has a decision making
rule which is used to decide the mode of commuting and receives payoff of her decision on choosing travel mode. Interaction among travellers, by group-based interaction, is one of factors that are predicted to influence choice behaviour of travellers. By introducing evolutionary approaches into travellers’ learning process, the model is expected to give informed insights into the way of solving social dilemmas of travel mode choice.

3. Agent-based simulation model

Our model consists of two parts: traveller model and transport model (Figure 1). In the traveller model, travellers choose mode based on the rules of expectations. After all travellers decide the mode of commuting, then travel time and payoffs are calculated in the transport model. These processes (iteration loop) are iterated 10 times for each generation. After that, an evolutionary process is utilized to evolve travellers’ type of expectations and to acquire adaptive behaviour of travellers by means of social learning mechanisms: conformist and payoff-biased transmission.

The generalized costs of travel by car and by bus are expressed as follows (1) (for details, please see [6]), respectively:

\[ V_A = K_{A0} + K_{A1}T_A \]
\[ V_B = K_{B0} + K_{B1}T_B + K_{B1}(P_{RB}/2) + K_{B3}W_B \]

(1)

where \( V_A, V_B \) are the generalized one-way travel costs of car and bus, respectively, \( T_A, T_B \) the one-way travel times by car and bus, respectively, and \( K_{ml} \) is the constant coefficient.

There are two types of belief that may represent individuals’ expectations: bandwagon expectations and opportunistic expectations. Three types of bandwagon expectations’ curve (pessimistic, normal and optimistic bandwagon) and one type of opportunistic expectations are to be investigated.

The influence of grouping on resolving a social dilemma of travel mode choice is studied by introducing a group-based interaction. A traveller interacts with other travellers of the same group in an imaginary spatial 3D plane named a “torus” plane, so that each traveller has eight surrounding neighbours who may influence her behaviour.
4. Simulation results and discussions

A number of agents, exactly 4096, are assigned into 16 homogeneous groups of 256. Each agent has a type of expectations’ curve: pessimistic, normal, optimistic bandwagon (for all experimental runs) or opportunistic (for the last run only), which is assigned randomly giving the same proportion of agents for every type of expectations curve. We run simulations with various initial levels of cooperation, ranging from 0.2 to 0.8 with increment of 0.1. The strength of conformist transmission ($\alpha$) ranges from 0.0 to 0.4. Simulations are run up to 100 generations with 10 iterations per generation. The economic rationality of travellers is simulated by payoff-biased transmission only ($\alpha=0$), where travellers always try to adopt behaviours with high payoff. Combination of payoff-biased and conformist transmission is demonstrated by using various value of $\alpha$ from 0.1 to 0.4.

For $\alpha=0$ and initial level of cooperation 0.2 - 0.7, the simulation runs result in the user-equilibrium point (Figure 2a). According to the user equilibrium theory, the number of bus users at the equilibrium point should be around 1200 or equal to 30% of travellers (dashed-line in the figure). A high initial level of cooperation (0.8) results in full level of cooperation because, for all types of curve, the probability of cooperating at 0.8 is higher than the criteria, so that all travellers suddenly cooperate.

At the end of simulation, it is found that all three types of curve still exist in most of the groups. The groups are also dominated by the pessimistic type with more than 50% of all travellers, followed by normal type with around 25% share and the rest being optimistic type. We also found two other findings from in-group dynamics: (a) local behaviours within a group may converge to all car users, all bus users or mixed users and (b) in-group cooperation level is related to existence of the type of curve. If the optimistic type dominates then it results in all cooperation, but if the pessimistic type dominates then it results in all defection.

The dynamics of cooperation level for $\alpha=0.1-0.4$, are also investigated. It is revealed that for $\alpha=0.4$ (Figure 2b) higher level of cooperation can be reached for all initial levels of cooperation. This shows also that the system may converge to other equilibrium points instead of the user-equilibrium point.

![Figure 2. Dynamics of cooperation level at (a) $\alpha=0.0$ and (b) $\alpha=0.4$.](image-url)

Observing in-group dynamics, it is revealed that early dynamical processes are complex and important to determine the succeeding processes and the end results of simulation. In some groups, optimistic expectations dominate, but in other groups, pessimistic or normal expectations also dominate. Conformist transmission helps the spread of a type of
expectations’ curve, and when the type is quite common and $\alpha$ is strong enough, the group becomes homogeneous with only one type of curve at the end of simulation. This result highlights the role of the conformist transmission on stabilizing cooperation with the condition that it should be strong enough compared with the payoff-biased transmission.

In another simulation run with $\alpha=0.4$, an opportunistic expectations’ curve is introduced in addition to existing bandwagons. It is revealed that the existence of opportunistic expectations produce a certain kind of characteristic for all initial levels of cooperation. The number of travellers using the bus reached around 60% (which is the maximum level of cooperation that still makes opportunistic agent cooperate rather than ‘free-ride’) in the early 50 iterations. Then, the number of bus users decreased and converged to a point lower than the case with only bandwagons, even though conformist transmission is also at work.

The existence of opportunistic expectations’ type creates considerably different system behaviour, since there is a chance for an agent to get higher payoff by ‘free-riding’ on others’ cooperation. Within a group, agents with this type basically prefer cooperation than defection, but they prevent the group converging to total cooperation, since they are better off ‘free-riding’ when they observe a high fraction of cooperation.

5. Policy and behavioural implications

The result of our simulation suggests the possibility that people may change their mode from car to bus just as a result of following others’ behaviour. They also may change their behaviour intentions from a pessimistic into an optimistic. This situation may apply during the implementation of some ‘soft’ travel demand management (TDM) measures, which are aimed at making people more conformist-oriented (bigger $\alpha$) and make people change their expectations into a more optimistic one.

Relating the idea of grouping population into several groups with group-based TDM measures, the simulation results shed light on the possibilities of getting in-group cooperation even though the measures require voluntary contributions. In relation to the travel awareness campaigns, a more local and personalized campaign aimed at groups of people (e.g. schools, companies, communities) may be more useful than a broad and national campaign aimed at whole population. Although the result would be small in scale, contributions of a group of people may diffuse to other groups and encourage them to cooperate and comply with the suggestions in the campaign (to reduce car-use).

From the view of knowledge contribution in travel behaviour study, this study has also shown the importance of considering interdependency between travellers. Travellers may take into account the choice of others and make decision based on expectations of others. The existence of social learning in travel behaviour is also an important factor that has never been considered in other studies before. This kind of learning may complement or sometimes replace individual learning.

6. Conclusion

An agent-based simulation model of travel mode choice has been built and applied to examining behaviour of travellers. When travellers are rational and using payoff-biased
transmission as the only learning mechanism, the system can reach the user-equilibrium point as predicted in the equilibrium analysis. However, there also exist some situations where the user-equilibrium does not exist, replaced by other equilibrium points. They happen when travellers consider the conformist transmission as the other social learning mechanism instead of the payoff-biased. Utilizing the observations on in-group dynamics, the model has also shown its capability to enrich understanding about the dynamics of mode choice behaviour and to obtain informed insights into resolving the social dilemma.

In a social dilemma situation of travel mode choice, a sudden, instantaneous and unpredictable change, which is usually called as an emergent phenomenon, may favour cooperation of individuals on choosing bus as their transport mode with several required conditions. They are: (1) beliefs and expectations in travellers’ decision making, especially optimistic bandwagon, (2) group-based interactions, and (3) conformist transmission.

In general, the agent-based model has provided important findings about the dynamics of travellers’ behaviour, which may not be gained by other approaches. The findings give some implications to the policy and the study of travel behaviour.

References