



INSERT CHAPTER NUMBER

ROLE OF MINORITY INFLUENCE ON THE DIFFUSION OF COMPLIANCE WITH A DEMAND MANAGEMENT MEASURE

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ABSTRACT

This study utilizes an agent-based approach to simulate behaviours of individuals. It is aimed to obtain some informed insights about the role of social interaction, social learning, and social influence on travellers' decision making to comply with a policy measure. A multiagent model which incorporates these social aspects is developed. The social interaction includes consideration of various interaction domains (e.g. neighbourhood, workplaces, or non-work activity clubs) and two sequential processes of interaction: meeting and communicating. In the social learning and influence, an investigation of the role of minority influence on the spread of compliance with a policy measure becomes a primary consideration. Aspect like inertia in decision making is also considered. An explorative behavioural survey has been conducted to obtain initial information regarding mechanisms of social interaction and social learning. Based on the survey, parameters and initial values of variables required for the simulation model have been estimated. The survey suggests that some individuals may be influenced by other people, who are relatively close to them, regarding travel-related decision. These close persons of an individual may have an opinion/expectation which can be important for the individual. Both empirical and theoretical findings are combined to develop a multi-agent simulation model. The results of simulation experiments suggest that the model is able to provide some informed insights about the spread of compliance with a 'soft' measure from an individual to other individuals and the diffusion from a group to other groups. Social interaction has been shown to have a major role in spreading compliance with the measure. The role of minority influence on eliciting compliance has been demonstrated in the experiments. A small number of influential individuals with consistency of choice on complying with the measure were able to diffuse





their choice to others. Also, a group that consists of influential agents was able to diffuse their compliance to other individuals from different groups. The results have also shown that a social club domain with a high frequency of repeated interactions between its members have an important role on the spread of compliance. Overall, the study has fulfilled its objectives and has also shown how we can incorporate social aspects, such as social interaction, social learning, and social influence, into modelling travellers' change of behaviour.

1. INTRODUCTION

Demand management measures are utilized to address the problem of people's car dependence by incorporating structural interventions ('hard' measures) as well as psychological interventions ('soft' measures). 'Hard' measures include policy interventions that alter the objective features of the decision situation by changing the incentive patterns associated with cooperation and non-cooperation. Examples of 'hard' measures may include changing payoff structure (e.g. congestion charging), reward-punishment (e.g. incentives for public transport users, restriction on car parking), and situational change (e.g. residential or workplace relocation). 'Soft' measures can be defined as policy interventions that are aimed at influencing attitudes and beliefs that may guide people's cooperative and non-cooperative behaviours. 'Soft' measures, which are more persuasive than 'hard' measures, can be implied by increasing individuals' awareness of the environmental impacts of excessive car use (e.g. travel awareness campaign) and providing advice and information to encourage the use of alternative modes than car (e.g. travel plan, individualized marketing) and alternative way of using car (e.g. car-sharing).

In this study, we argue that the effectivenesses of 'soft' measures may be enhanced if more consideration and emphasis is given to the support of social aspects of human behaviour. Given the fact that behavioural change does not take place in a social vacuum, broader society and its social values have important roles to play. Social aspects, including *social interaction*, *social learning/imitation*, and *social influence*, may influence travellers' decision making and behaviour. Within social influence, emphasis shall be put on *minority influence* as this type of social influence may have an important role in spreading compliance with a soft measure. In the minority influence, a few individuals (independently or in group) have influencing power built on their reputation to induce compliance in the population (Sampson, 1991, pp.151-163). Better understanding of these aspects will provide us with some informed insights about the potential for utilizing them to encourage travellers' compliance.

The idea of utilizing a simulation model to better understand the impact of a demand management measure on travellers' behaviours has not been given much consideration until recently, despite its potential to provide a different 'flavour' on travel behaviour studies by deriving informed insights from simulation experiments (e.g. Kitamura *et al.*, 1999; Sunitiyoso and Matsumoto, 2005). In studying the effects of a treatment/intervention on individuals, a simulation experiment offers extension to a laboratory experiment since it is able to handle the interactions of a large number of individuals with each other and with a





transport system. It also makes possible for conducting a large number of repetitions (time periods), which enable the researcher to observe whether individuals' choices converge to an equilibrium point or not, how they converge and the dynamics before convergence, and how many repetitions are required to reach the convergence point. A simulation approach may also give predictive benefit to forecast travellers' behaviour in different kind of situations and to know how robust the results of the laboratory experiments are in other parametric conditions.

The diffusion process of compliance with a demand management measure has become our interest as it may have important role in encouraging behavioural change. Jones and Sloman (2003) argued that the existence of the 'snowball effect', a phenomenon where long-term effects may be greater than short-term ones, would increase the effectiveness of 'soft' measures over time. They stated that there is some evidence that the change may be very slow at first, but then accelerate as people see their colleagues and neighbours changing their travel behaviour. In the implementation of voluntary travel behaviour change programs, Ampt (2003) argued that strategies that require households to diffuse information both between households and ultimately across communities are likely to be sustainable. Spreading information by 'word-of-mouth' has been argued to be most effective way for diffusion and reinforcement (Stern et al., 1987). When a person tells someone about what she is doing, she is both reinforcing her own behaviour in the process and giving a level of commitment. Involving key people (not necessarily traditional leaders, but 'trusted others' in the community) will provide more advantages since people are more willing to hear from someone who is trusted, respected or perceived to have similar values. This is related with the idea of minority influence where a few influential agents are able to influence the opposing majority to the minority's way of thinking. Stopher (2005) added the importance of diffusion effects in the implementation of voluntary programs by stating the need to measure the effects in schools, workplaces, and other locations. A study by Shaheen (2004) also considered this word-of-mouth communication as a means to diffuse the change of behaviour in a car-sharing programme. Taniguchi and Fujii (2007) in their study of promoting community bus service found that word-of-mouth advertising through recommendations to friends and family plays an important role in promoting bus use. This interaction process may have begun a chain of bus use and recommendations. In modelling, Ellison and Fudenberg (1995) developed a formal model of the influence of word-of-mouth communication structure in social learning. Their paper discusses the way that word-of-mouth communication aggregates the information of individual agents. They found that word-of-mouth communication may lead all agents to adopt the action that produces socially efficient outcomes. This tends to occur when each agent receives limited information about other agents.

A way of spreading information which is commonly used is by media (e.g. newspaper, radio, TV, etc), as often used in social norms media campaigns (e.g. DeJong, 2002). However, this study does not address this way of communicating. It is looking at the diffusion of information directly from person to person.





The structure of this chapter consists of seven sections. Following an introduction in this section, the hypotheses underlying the research as well as the research objectives are discussed in Section 2. Section 3 presents the general framework of the study and the main concepts such as social interaction, social learning and influence, and individuals' decision making process. Section 4 provides discussions about the simulation model, followed by Section 5 which discusses model's parameters and variables. Simulation results are analyzed and discussed in Section 6. The chapter is closed with conclusions and future research in Sections 7 and 8 respectively.

2. HYPOTHESES

The study aims at investigating the following hypotheses:

- a. Social aspects, mainly *social interaction*, *social learning/imitation* and *social influence*, may influence travellers' decision making and behaviour.
- b. *Repeated social interactions* between individuals generate a high propensity for communicating which later give more opportunity to induce compliance in the population, since communication enables exchanges of information between individuals and provides a means of social learning/imitation.
- c. *Minority influence*, a type of social influence, may have an important role in spreading compliance with a soft measure. A few influential individuals with a good reputation derived from their consistency on complying with the policy measure may influence other individuals' decision of whether to comply or not.

Based on those hypotheses, research objectives are derived. The main objective of this study is to obtain informed insights on the influence of social interaction and social learning in travellers' decision making to comply with a soft measure by utilizing an agent-based approach to simulate behaviours of individuals. This primary objective can be splitted into two sub-objectives:

- a. To provide a model of <u>social interaction</u> with respect to travel decision making, which includes the consideration of :
 - various interaction domains: neighbourhood, workplaces/schools, non-work/non-study activity clubs;
 - processes of interaction: meeting and communicating.
- b. To develop a model of <u>social learning and social influence</u> in the context of travel choice behaviour, which primarily includes the investigation of the role of minority influence on spreading compliance with a soft measure. Aspect like inertia in decision making is also considered.

3. GENERAL FRAMEWORK AND MAIN CONCEPTS

Figure 1 presents the general framework of the study. Two main focuses are *social interaction*, which consists of the process of meeting and communicating, and *social learning/imitation* and *social influence*, where imitating/learning and influencing process may





occur between individuals. Individual's own experience is also being considered, however it is rather simplified. Social learning and social influence, together with individual's experience-based learning, affect the individual's preference that later influence her behaviour. Other factors, such as costs, values, attitudes, social norms, habit, personality traits, and constraints, may also influence individuals' preference. However, since not being the scope of this study, these factors are not included in the research framework.

The framework is a snapshot of an individual's dynamic responses. The processes in the framework are iterative processes of adaptation to the changes of decision making environment caused by own experience and other people decisions/behaviours, as well as changes in travel environment caused by a policy intervention. In this study, we focus on the period of time where a policy measure is being applied, particularly a 'soft' measure. However, it is not restricted to a 'soft' measure. It is also applicable to a situation where a structural change produced by a 'hard' measure has been applied and the effects of cost change have been minimized (e.g. people has already got used to a new travel cost resulting from the structural change and become less sensitive to the cost difference).



Figure 1 General framework

3.1. Social interaction

In this study, we consider that social interactions occur beyond residential neighbourhoods. There may be multi-dimensional relationships between individuals, which are built based on similarities of 'social club' domains, including workplace, non-work activity club and also within a household. Since this study does not focus on intra-household interactions, interactions within members of a household are not included in the model. Social club membership may be initiated by some key events during a life course (for reference about key events, see Van der Waerden *et al.*, 2003; Stanbridge *et al.*, 2004). For example: moving house initiates new neighbourhood relationship, a new workplace or a new school implies the probability of repeated interactions with schoolmates, etc. Becoming a new member of a





group such as family, work, or other social clubs, automatically creates social links between the new and existing members of the group. Arentze and Timmermans (2006) argued that the links exist as long as the membership holds and may or may not sustain beyond the membership period depending on the extent they are being reinforced over time. In this internet era, the 'online' social network domain has also arisen and is used in some research studies (e.g. Tian *et al.*, 2003).

The possibility of repeated and frequent interactions between individuals differs from one social club to another. For example, a workplace gives more opportunity for interaction than a sport/leisure club since colleagues in the same workplace spend around five days a week, whereas members of sport/leisure club may only meet less frequently. With each individual involved in various interaction domains, compliance in a group may diffuse to other groups during repeated processes of interaction. Figure 2 shows an illustration of multi-domain interactions between three individuals (A, B, and C) as well as possible frequencies of interactions within each domain. Domains of interactions are not limited to those which are illustrated in the figure. Social interactions with friends or relatives in other domains may also exist and exert influence.



Figure 2 Illustration of a multi-domain social interaction and social learning/influence

In the simulation model developed in this study, social interaction is represented by two processes: *meeting* and *communicating*. These processes may occur in any social club domain depending on the day of the week whenever agents (who represent individuals) involve with activities in the domain. Meeting is defined as a process where two agents meet each other without engaging in an intensive communication involving an exchange of information. Communication may follow the meeting if there is a 'mutual agreement' between them, which depends on whether they are both closely connected or not (represented by the value of perceived degree of relationship) and on whether a threshold for communicating has been exceeded or not. Arentze and Timmermans (2006) described different criteria to achieve





mutual agreement. They argued that the agreement can be achieved if both agents consider that the expected utility of the interaction (communication) compensates for the loss in discretionary time and the effort involved. The criteria used in this study are simpler and probably more realistic since individuals may not be too 'rational' regarding social interaction (meeting and communicating) for the sake of utility gained from the interaction, instead a simple reason, such as the feeling that they are closely related, may start communication. Table 1 shows the possibility for communicating which depends on the value of perceived degree of relationship and threshold and relationship. The higher the threshold is, the lower the possibility for an individual to have a communication with another individual. The higher the perceived degree of relationship is, the higher the possibility for communicating.

As social network may affect the spread of influence (Kempe *et al.*, 2003), the structure of network has an important role to determine a successful diffusion of compliance. There are many kinds of communication structure that may exist between individuals. In this study, it is assumed that within the neighbourhood domain individuals may meet (but not necessarily followed by communication) their neighbours in a lattice-structured network. Imagine that each individual occupies a cell in a 2D plane, Figure 3a illustrates a lattice-structured social network between an individual (called A) and her/his immediate neighbours (B, C, D, E, F, G, H and I). While in other types of social club (e.g. workplace, non-work social club) they meet any other member in random manner (complete mixing). This is illustrated in Figure 3b where individual A has a complete mixing network with individual J, K, L and M which are located in dispersed cells on the 2D plane.

		Threshold for	
		communicating	
		Low	High
Perceived degree of	Low	Medium	Low
relationship	High	High	Medium

Table 1 Possibility for communicating



Figure 3 Illustration of social interactions through lattice-structured and complete mixing networks

A study by Blonski (1999), which utilized the Case Based Decision Theory (CBDT) developed by Gilboa and Schmeidler (1995) for investigating social learning process through different communication structures, reported an important finding in relation to the effects of communication structure on the spread of influence. There is a communication structure called 'star' structure, where each individual is informed only about his own actions and the action of one distinguished agent, called the 'star'. There is no communication between agents except with the star. This distinguished agent has the power of manipulating the direction of social learning. The agent does not face a choice problem and is not subject to any stochastic shocks. It has been reported that the star communication structure was able to generate a high level of cooperation. This study is in line with our proposed study on investigating minority influence, since the 'stars' may represent a minority with high influencing power. However, agents do not necessarily communicate with stars only, but they may also communicate with other common agents.

3.2. Social learning and social influence

An agent may learn individually from her own experience and learn socially from information gained during communication with other agents. The concept of learning suggests that individuals learn from their past experience and acquire an adaptive decision making process to cope with uncertain nature of environment (Arentze and Timmermans, 2005). In transport field, individual learning concept has been utilized in the context of mode choice, route choice and departure time choice (e.g. Akiyama and Tsuboi, 1996; Verplanken *et al.*, 1997; Fujii *et al.*, 2001; Nakayama *et al.*, 2001; Srinivasan and Guo, 2003; and Avineri and Prashker, 2005). On the other hand, incorporation of the social learning concept in travel behaviour studies is still a challenge as it has not been investigated intensively, although evidences from other disciplines (e.g. Pingle, 1995; Pingle and Day, 1996; Offerman and Sonnemans, 1998;





Smith and Bell, 1994; Kameda and Nakanishi, 2002, 2003) have shown that this kind of learning is influential and important. In social learning, decision makers may have the opportunity to observe the behaviours or preferences of others prior to making a choice.

There is a slight difference that can be drawn between social learning and social influence. In social learning, the change of judgments, opinions and attitudes of an individual is a result of active search for information by the individual, where as in social influence, the change is a result of being exposed to those of other individuals (Van Avermaet, 1996).

Social influence is more than the majority's efforts to produce conformity on the part of a minority; it is also a minority's effort to convert the majority to its own way of thinking (Sampson, 1991). In this research, minority influence becomes the point of interest. Minority influence is investigated by introducing a situation where a few influential agents (independently or in group) have more power to influence others whom they communicate with. The strength of their influence is derived from the reputation built from their consistency of choice to comply with the measure (Van Avermaet, 1996; Sampson, 1991, p. 155). An influential individual is not necessarily a traditional leader, but she can be a 'trusted person' with a respected reputation in the social club. Individuals are more willing to hear from someone who is trusted and respected as a consistent person. For example: a suggestion to car share by a consistent car sharer, who has been car sharing regularly in a considerable period of time, would have more influence than that of other individuals' who have not done so.

Latané and Wolf (1981), in the first principle of their Theory of Social Impact - Principle of Social Forces, argued that social impact is a multiplicative function of three factors: strength (e.g. power, expertise), immediacy (proximity in space and time), and size (number of the influence sources). The principle shares the same idea with Tanford and Penrod (1984)'s Social Influence Model (SIM). However, Tanford and Penrod's theory is more formal and it is based on certain features presumed to exist in any majority and minority influence situation, such as group size, number of influence sources, probabilities that a majority member will choose the minority position without any influence attempted by the minority, and individual differences in members' susceptibility to persuasion. The minority influence may have smaller number of influence sources than majority, but it may still rely on strength (power to influence derived from reputation) and immediacy (closeness of relationships between individuals).

3.3. Decision making process

The decision of whether to comply with a demand management measure is made based on the individual *i*'s preference value (P_i). Each individual learns individually from past decisions, learns/imitates other agents' decisions and is influenced by 'influential' individuals, and then updates her preference value in a reinforcement process. The higher the preference to comply is, the more the probability that the individual will comply with the measure.



The decision making of each agent is based on a social influence model with each agent takes into consideration previous choices and choices of other people. The model is based on Gordon *et al.* (2004)'s social influence model. Considering difficulties on measuring some of the original model's parameters, assumptions are used to simplify the model. We modify and extend the Gordon *et al.*'s model by adding an individual experience term, so that the model can be formulated as:

$$C_{it+1} = f\left(\frac{1}{\left\|\mathcal{G}_{i}\right\|}\sum_{j\in\mathcal{G}_{i}}\beta_{ij}C_{jt},\beta_{ii}C_{it}\right)$$
(1)

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where:

 C_{it} : decision/choice of individual *i* at time *t*

(binary choice, $C_{it} \in \{0,1\}$; multiple *n* choice, $C_{it} \in \{0,1,\ldots,n\}$)

 \mathcal{G}_i : set of individual *i*'s neighbours/colleagues/friends ($\mathcal{G}_i \subseteq S$)

S: set of agents in the population

 β_{ij} : weight given by individual *i* to the recent choice of individual *j* ($\beta_{ij} \in [0,1]$)

 β_{ii} : weight given by individual *i*'s to her own recent choice $(\beta_{ii} \in [0,1]; \sum \beta_{ij} + \beta_{ii} = 1)$.

In the model, interactions between two or more agents are treated in one-to-one interaction basis. For example, interactions between individuals *i*, *j*, and *k* are considered as three interaction processes: $i \leftrightarrow j$, $i \leftrightarrow k$, and $j \leftrightarrow k$. So that, there will be only a pair of individuals in each interaction (*N*=2). The number of individual *i*'s neighbours/colleagues/friends in each single interaction is only 1 ($||G_i|| = 1$), since the interaction is one-to-one. Then Equation 1 becomes:

$$C_{it+1} = f(\beta_{ij}C_{jt}, \beta_{ii}C_{it}); \ i \neq j$$
(2)

where *j* is a single individual with whom individual *i* interacts.

This research considers that every single choice of own and other individuals contributes to the change of individual *i*'s preference at time $t(P_{it})$ in an individual learning process from time to time. Since the processes of individual and social learning may take place at the same time, there are two processes of updating P_i by using a simple weighted updating mechanism in this equation:

$$P_{it+1} = \begin{cases} (1 - \beta_{ij})P_{it} + \beta_{ij}C_{jt} \Leftarrow i \neq j \\ (1 - \beta_{ii})P_{it} + \beta_{ii}C_{it} \Leftarrow i = j \end{cases}$$
(3)

The first part of Equation 3 applies whenever individual *i* interacts with individual *j* and puts the choice of individual *j* into consideration following a process of social learning or social influence. The other part represents a simple individual learning process of individual *i*'s whenever she makes a decision/choice. The choice of individual *i* at time t+1 (C_{it+1}) depends



on her preference value at that time (P_{it+1}) . A uniform-distributed U[0,1]'s random number x is generated and then compared with the preference value using Equations 4 to decide whether to comply $(C_{it+1} = 1)$ or not to comply $(C_{it+1} = 0)$.

$$C_{it+1} = \begin{cases} 1 \Leftarrow P_{it+1} > x \\ 0 \Leftarrow P_{it+1} \le x \end{cases}$$
(4)

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The decision making process of each individual is repeated from time to time. The preference to comply with a demand measure (P_{it}) is also updated when the individual makes decision as well as when she/he learns from (is influenced by) other indviduals. However, the population of individuals also displays inertia, where only a number of them make a decision and the others continue with their previous choice. And also each individual does not have perfect information about the choice of all other individuals in the population. She/he only knows the choice of other individuals whom she communicates with.

As the emphasis of this study is on exploring the spread of compliance during the implementation of a 'soft' policy measure, which may not incur any economic cost to the travellers, we do not assume any specific utilities or payoff consequences (e.g. cost, earning or other outcomes in amount of money) of every choice made by an agent. In some studies, payoff or cost consequences are not used in order to avoid a cost-driven situation which may hinder the investigation of the social aspects being studied, as well as to avoid too many complications (e.g. Axelrod, 1997; Nakamaru and Levin, 2004). Moreover, in some situations, people may not economically rational to make a travel-choice decision. As the choice in the model is a binary choice of whether to comply or not to comply, for simplicity, a score of one ($C_{it} = 1$) is given to compliance and zero ($C_{it} = 0$) to non-compliance.

The model is a simple social influence model where each agent only takes into consideration previous choices and choices of other people, without considering the outputs of the choices. The model is neither based on reinforcement learning theory nor utility theory. It contains a process where preferences are updated based on choices, which deviates from an assumption of reinforcement-learning theory that the value of an action is updated each time an action is chosen based on perceived rewards (not based on choice of the action). Utilities are also not represented in the model, only tendencies to repeat earlier behaviour or behaviour of others. However, for future development, utilities of agent's action (e.g. cost, earning) shall be considered in the model. In addition, reinforcement learning models (e.g. heuristic, weighted-return, and average-return) may be incorporated into the modelling of agents' decision-making algorithms.

4. SIMULATION MODEL

The model consists of three main sections: social interaction, social learning and influence, and decision making. Figure 4a-b presents the algorithm of the developed model. The





algorithm starts with initialization process of assigning a number of agents into the social interaction domains (also referred as 'social clubs'), such as *residential neighbourhood*, *workplace/school* and *other activity clubs*.

In the initialization process, a value of global parameters (e.g. size of the minority N_m) and an initial value of global variables (e.g. level of compliance *LC*) are set. A population of agents (*S*) is then generated (virtually in a grid space) and given attributes (parameters and initial variables). A value of individual parameters (*TH_i*, *REP_i*, β_{ij} , α_{ij} , and γ_{ij} ; see Table 2 in Section 5 for description of these parameters) and an initial value of individual variables (*P_i*, *R_{ij}*, *tDec_i*, and *C_i*; see Table 3 for description) are assigned to every single agent *i*.

There are two types of agent: an influential agent (which is a member of the minority) and a common agent. An influential agent is given reputation $REP_i = 1$ and a common agent is given $REP_i = 0$. REP is used to decide the direction of learning/influence during the process of social influence. In the model it is assumed that the direction of learning is from the partner to the initiator. However, individuals with a high REP (minority agents) are able to force the direction of learning from them to other (common) agents. The number of influential agents is according to size of minority (N_m). Each simulation run is a period of T days, which on each day an agent may involve in one or more interaction within one or more domains of interaction.

A social interaction process starts when an agent (for example, agent *i*) involves in an activity within a 'social club' domain on day *t*. Agent *i*, who is the initiator, chooses a partner (agent *j*) randomly from its neighbours (for lattice structured network) or anyone of other agents (for complex mixing network). Technically, it is conducted one by one, from *i*=1 to *N*. They are then meeting each other. Perceived degree of relationship (R_{ijt}) of two interacting-agents is then updated. Each meeting reinforces perceived degree of relationship of both agents with reinforcement factor $\alpha = 0.9$ ($R_{ijt} = \alpha R_{ijt-1} + (1-\alpha).1$). On the next day (*t*+1), it decays over time with decaying factor $\gamma = 0.999$ ($R_{ijt+1} = \gamma R_{ijt}$).

Both agents *i* and *j* check whether or not their perceived degree of relationship (R_{ijt}) exceeds their thresholds for communicating $(TH_i \text{ and } TH_j)$ in order to decide whether or not they will communicate about travel related decision. Thresholds are assumed to be randomly U[0,1] distributed. If $R_{ijt} > TH_i$ and $R_{jit} > TH_j$, then communication involving exchange of information will follow. Otherwise, they will not communicate about their travel decision. On the same day, agent *i* may then have another interaction with another agent (say, agent *k*) which takes place in the same or another domain of interaction.

The process of social learning and social influence may exist during a process of communication between two agents, *i* and *j*. If both of communicating agents have the same choice on day *t*-1 ($C_{it-1} = C_{jt-1}$) then they are reinforcing each other ($P_{it} = (1-\beta_{ij}).P_{it-1} + \beta_{ij}.C_{jt-1}$ and $P_{jt} = (1-\beta_{ji}).P_{jt-1} + \beta_{ji}.C_{it-1}$). If they have different choices, there are two possibilities. First, if one of communicating agents has a higher reputation than the other ($REP_i > REP_j$ or $REP_i <$



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 REP_j) then the exchange of information will only be one way, from the agent with higher reputation to the other with lower reputation $(P_{it} = (1-\beta_{ij}).P_{it-1} + \beta_{ij}.C_{jt-1})$ or $P_{jt} = (1-\beta_{ji}).P_{jt-1} + \beta_{ji}.C_{it-1})$. The process is called social influence. Second, if they both have the same reputation, then only the agent who initiates the social interaction learns from partner's choice by updating its preference $(P_{it} = (1-\beta_{ij}).P_{it-1} + \beta_{ij}.C_{jt-1})$, since the initiator is considered as the one who is looking for information.

The decision making process considers that the population of agents may display inertia, where only a fraction of agents considers changing decision at the same time. The other fraction of agents continues with their previous choices. The time between each decisionmaking (*tDec_i*) of each agent follows an exponential distribution with mean $\lambda = 0.0714$. The mean value of the distribution is derived from the assumption that in average each agent considers changing its decision twice in a month (four weeks) or one in 14 days (1/14 =0.0714). In every iteration, each agent checks whether or not the current iteration is the time to make a decision, which may result in the same choice as previous decision or a different choice. If this is the case $(t = tDec_{it})$, then the agent proceeds to a process of decision making based on preference using a random utility model of decision making. A uniform-distributed U[0,1]'s random number x is then generated. If $P_{it} > x$ then agent i chooses to comply ($C_{it} =$ 1), otherwise, not to comply $(C_{it} = 0)$. Preference at time $t(P_{it})$ is again updated $(P_{it} = (1 - 1))$ β_{ii}). $P_{it} + \beta_{ii} C_{it}$). After making a decision, the timing for next decision is generated and the process loops back to the beginning of social interaction. If it is not a decision making time $(t \neq tDec_{it})$, then the process loops back to the starting process of social interaction and the decision time will be checked again at t+1 ($tDec_{it+1}=tDec_{it}$).

Based on this simulation model, a numerical experiment is conducted to demonstrate how the model works and provide some informed insights about changes of travellers' decision and behaviour on complying with a 'soft' measure, in this case, a car sharing programme within a university.



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Figure 4a Flowchart of social interaction, social learning and social influence



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Figure 4b Flowchart of decision making process

5. SETTING VALUES TO THE MODEL'S PARAMETERS AND VARIABLES

Before developing the model, a university-based behavioural survey with students as respondents (*N*=178) has been conducted to obtain information regarding mechanisms of social interaction and social learning in addition to those derived from literatures, as well as to set values of parameters and variables required for the simulation model. The respondents are students in the Faculty of the Built Environment, University of the West of England - Bristol. Car-sharing, as a 'soft' demand management measure, was used as a case study in the survey and is used in the simulation model. The survey suggests that some individuals may be influenced by other people, who are relatively close to them, regarding travel-related decision. These close persons of an individual may have an opinion/expectation which may have some level of importance to the individual. The initial level of compliance with a soft measure is also estimated from the survey results.





Examples of the survey results are given in Figures 5 and 6. Figure 5 shows respondents' expectation that the persons that are particularly close them may have an opinion about the way they travel to the University. In the family category, around 80 respondents (44%) have a close person in her family who may have at least a weak opinion about her travel choice. A similar trend happens in the housemate, coursemate and other friend category. Although in each category the majority of respondents (more than 100 persons) do not expect that a close person in each category has any opinion, there are actually 41% of respondents who answer no opinion to all categories. So that there are 59% of respondents have at least a close person who may have (at least) a weak opinion about their choice of travel.

When respondents are asked about the importance of other people's opinion, at least in one category there are 30% to 49% of respondents consider close people's opinion (at least) slightly important on their decision about the way to travel to the University (Figure 6). Around 37% of respondents consider that their close persons' opinion about their travel mode choice is unimportant for them in all categories, so that majority of respondents (63%) have at least a close person whose her/his opinion is (at least) slightly important.



Figure 5 Close persons may have opinion (0=no opinion, 1=weak opinion, 2=somewhat strong, 3=quite strong, 4=strong opinion)



Figure 6 Importance of close persons' opinion (0=unimportant, 1=slightly important, 2=somewhat important, 3=quite important, 4=important)

The behavioural survey has provided some of model's parameters and initial values for the variables, while others are based on theoretical assumptions, as they are very difficult to be measured empirically. The following explanations highlight the way of deriving the parameters and initial values of variables for the simulation model.

Initial values of an individual's preference (P_i) is derived from the question of "how inclined are you to join a car-sharing programme?" Based on the answers (definitely not join, probably not join, possibly not join, neutral, possibly join, probably join, and definitely join), a 7-level of preference is obtained (0, 1/6, 1/3, 1/2, 2/3, 5/6, and 1). The average preference to car share is 0.47. Respondents who "regularly car-share but have only begun to do so in the last 6 months" or "regularly car-share and have been doing so regularly for 6 months" are considered to have a decision to car-share ($C_i = 1$) as an initial value. There are 31 respondents satisfy one of these criteria, so that the initial level of compliance (LC) is 17.41%. The level of compliance is simply calculated as a percentage of the number of car sharers in the population of respondents (or agents in the simulation).

The size of minority (N_m) in the survey is defined as the number of individuals who are "regularly car-share and have been doing so for 6 months" and have initial preference value (P_i) from 5/6 to 1. From the survey, we found that $N_m = 6.18\%$. Respondents who are members of the minority are given a reputation value of one $(REP_i = 1)$. Others are given zero value of reputation $(REP_i = 0)$. Weight of the influence of agent *j*'s choice on agent *i*'s preference (β_{ij}) is derived from respondents answer about "the importance of a close person" opinion/expectation on their travel choice to get to the university." Five-level of weight is obtained (0, 1/4, 1/2, 3/4, and 1).

Tables 2 and 3 highlights parameters and variables of the simulation model respectively.





Table 2	Model parameters		
Parameter	Description	Source	Value assigned to model
TH _i	Threshold for communicating	Randomly	$TH_i \in U[0,1]$
	of agent <i>i</i>	assigned	
REP _i	Reputation of agent <i>i</i>	Survey results	$\text{REP}_i \in \{0,1\}$
			0 = common individual
			1 = influential individual
β_{ij}	Weight of the influence of	Survey results	$\beta_{ij} \in [0,1]$
	agent <i>j</i> 's choice on agent <i>i</i> 's		
	preference		
α_{ij}	Reinforcement factor of R _{ij}	Assumed	$\alpha_{ij} \in [0,1]; \alpha_{ij} = \alpha$
	(see Table 3)		For experiment, $\alpha = 0.9$
β_{ii}	Weight of influence of agent	Assumed	$\beta_{ii} \in [0,1]; \beta_{ii} = \beta_i$
	<i>i</i> 's previous choice on its		For experiment, $\beta_i = 0.1$
	preference		
γ _{ij}	Decaying factor of R _{ij}	Assumed	$\gamma_{ij} \in [0,1]; \gamma_{ij} = \gamma$
			For experiment, $\gamma = 0.999$
N_m	Size of minority	Survey results	$N_m \in (0, 50\%)$
			From survey, $N_m = 6.18\%$

Table 3 M	Iodel variables
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Variable	Description	Source	Value assigned to model
P _{it}	Preference of agent <i>i</i> at time <i>t</i>	Survey results (initial value)	$P_{it} \in [0,1]$
R _{ijt}	Perceived degree of relationship by agent <i>i</i> about its relation with agent <i>j</i> at time <i>t</i>	Randomly assigned (initial value)	$R_{ijt}\!\in\!U[0,\!1]$
tDec _{it}	Timing of decision making of agent <i>i</i> at time <i>t</i>	Assumed exponentially distributed	$\lambda = 0.0714$ tDec _{it} = -ln(x)/ λ +t
C _{it}	Decision/choice of agent <i>i</i> at time <i>t</i>	Survey results (initial value)	$C_{it} \in \{0,1\}$ 0 = not to car-share 1 = to car-share
LCt	Level of compliance at time <i>t</i>	Survey results (initial value)	$LC_t \in [0\%, 100\%]$ Initial value = 17.41% (= Σ initial C _i /N _s)

Note:

 $i \neq j$; $i, j \in S$ (i = subject (initiator); j: partner; S: population of agents).





6. SIMULATION RESULTS AND DISCUSSION

In the simulation model, a number of agents ($N_s = 4096$) are generated and given attributes (parameters and initial variables) according to the attributes of respondents (N=178) in the survey. So that approximately each respondent has 23 'clones' ($N_s/N = 4096/178 \approx 23$) in the population of agents. Each simulation run is a period of T = 1460 days (4 years). The interaction domains ('social clubs') used in the model is limited to the domains used in the university context used in the behavioural survey. They are *residential neighbourhood, course of study* and *non-study activity club*.

There are 4 x 7 possible scenarios based on the existence and location of influential minority: a) no minority, b) minority spread in the population, c) minority exist only in a particular course of study, and d) minority exist in several non-study activity clubs; and based on the domain of interactions: a) neighbourhood, b) course, c) non-study activity club, d) combination of neighbourhood and course, e) combination of neighbourhood and non-study activity club, f) combination of course and non-study activity club, and g) all three domain together. Another scenario where social interaction does not exist will also be presented. In this study, the setting of simulation is limited into 8 scenarios as in Table 4.

In the neighbourhood domain, agents interact in a lattice structure network where each agent has 8 neighbours surrounding it. Agents who are located on the edges of the plane have less than 8 neighbours. Interactions in a course of study and a non-study activity club are in a *complete mixing network* (random manner), where an agent can meet any other agent within similar course or club. The average frequency of interaction in each domain per week is: 2/7 within neighbourhood, 4/7 within course of study and 1/7 within non-study activity club. There are 16 courses of study having approximately 256 students per course and 64 non-study activity clubs having approximately 64 members per club. Each scenario is repeated for 10 runs.

Table 4	Scenarios of simulation run		
Scenario	Existence and location of	Interaction domain (neighbourhood,	
	influential minority	course of study, non-study activity club)	
1	No	No social interaction	
2	No	All domains	
3	Yes, spread in population	All domains	
4	Yes, spread in population	Neighbourhood only	
5	Yes, spread in population	Course of study only	
6	Yes, spread in population	Non-study activity club only	
7	Yes, only in a course of study	All domains	
8	Yes, only in several non-study	All domains	
	activity clubs		



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6.1. Effects of social interaction and influential minority agents (Scenarios 1 - 3)

Figure 7 presents the results of Scenarios 1 - 3. The results presented in the figure is only for the first 365 days (1 year) of simulation run, since the system is static after that until the end of the run (1460 days = 4 years). Each point in the graph is an average of 10 simulation runs. In Scenario 1, where social interaction between agents does not exist, the number of car sharers goes up gradually up to 2008 agents (level of compliance LC = 49.0%) at the last 90 days the simulation run (Note: results of all scenarios can be found in Table 5). When social interactions (in all domains of interactions: neighbourhood, course of study, and non-study activity club) exist between agents (Scenario 2), the number of car-sharers increases with a slower trend than in Scenario 1. However, the level of compliance in this scenario is higher than in Scenario 1 with 2290 car sharers (LC = 55.9%). The situation becomes better for car sharing when a number of influential minority agents (6.18% of total) exist in the population as seen in Scenario 3. These influential minority agents are able to increase the level of compliance up to in average of 2514 car sharers (LC = 61.4%).



Figure 7 Level of compliance (LC) in Scenarios 1-3 (Note: scenario numbers in parentheses)



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Table 5	Results of simulation runs	
	(average of the last 90 days)	
Scenario	Number of car LC (%)	
	sharers	
1	2008	49.0
2	2290	55.9
3	2514	61.4
4	2289	55.9
5	2395	58.5
6	2285	55.8
7	2425	59.3
8	2481	60.6

Average preferences of agents (Figure 8) in Scenarios 1 - 3 reach almost similar points to their levels of compliance (Figure 7), since they are highly correlated based on the fact that the decision of each agent is made based on its preference. In Scenario 1, where social interaction does not exist, the average of preference is stable day to day with an average of 0.49 in the last 90 days of simulation runs. This result is close to the initial average preference based on survey results, which is 0.47. Scenarios 2 and 3 have similar patterns of changes. In early interactions, average preferences in these scenarios decrease since majority of agents, who have a low preference to car-share, decide not to car share causing the decrease of average preference. After the effects of initial condition can be minimized, as agents involve in interactions with each other, the average preferences in Scenarios 2 and 3 increase higher than that of Scenario 1. When influential minority agents are in charge, a higher level of compliance can be achieved in Scenario 3 (with minority) than that of Scenario 2 (without minority).



Figure 7 Average preferences to car-sharing in Scenarios 1 - 3

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Similar to Scenario 3, Scenarios 4 - 6 represent a situation where influential minority agents exist in the population of agents (Figure 9). The effects of interaction domains are studied by comparing the system's behaviour whenever interactions happen in different sets of domains. Level of compliance has the highest level in Scenario 3 where all domains of interaction (neighbourhood, course of study and non-study activity club) are in use. It is followed by Scenario 5 where the domain is course of study. In this scenario, the level of compliance has almost similar path to Scenario 3 in the first 100 days, but then the rate of increase in Scenario 3 is faster than in Scenario 5. Scenario 5 ends up with 2395 car sharers (LC = 58.5%). Neighbourhood domain (Scenario 4) and non-study activity club domain (Scenario 6) have similar paths in the first 100 days of simulation and almost similar levels of compliance, 55.9% and 55.8% respectively.



Figure 9 Level of compliance (LC) in Scenarios 3 - 6

6.3. Effects of interaction domains (Scenarios 3, 7 and 8)

We investigate the effect of location of influential minority agents to the results of simulation by running simulation runs with a scenario where minority agents are located within a course of study (Scenario 7) and another scenario where they are located in several non-study activity clubs (Scenario 8). In Scenario 7, all influential minority agents ($6.18\% \approx 254$ agents) are allocated in a course of study, whereas in Scenario 8, they are allocated in 4 non-study activity clubs with 64 members each. Figure 10 shows the results of simulation runs with these two scenarios compared with a scenario where minority agents spread in the population (Scenario 3).

Scenario 3, 7 and 8 give almost similar results. Only small differences in the dynamics can be seen in these scenarios, in terms of the pattern of changes as well as the end results. However,



when minority agents only exist in a course of study as in Scenario 7, the level of compliance is slightly lower than that of Scenario 8.

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Overall, there is no significant effect of the minority agents' location that can be reported based on the results in these scenarios.



Figure 10 Level of compliance (LC) in Scenarios 3, 7, and 8

7. CONCLUSIONS

The results of simulation experiments suggest that the model is able to provide some informed insights about the spread of compliance with a 'soft' measure from an individual to other individuals through various kinds of interaction domain. Social interaction has been shown to have a major role in spreading compliance with the measure. It is also found that the existence of influential minority agents in the model increases the level of participation within population of agents.

A small number of influential individuals, who were located randomly in the population, with consistency of choice on complying with the measure were able to diffuse their choice to others. Also, a group that consists of influential agents was able to diffuse their compliance to other individuals from different groups. A 'social club' domain with a high opportunity of repeated interactions between its members, like course of study, has been reported to have an important role on the spread of compliance. Neighbourhood is a domain which has often been used in existing simulation models, however it may have smaller role than course of study since the interactions between neighbours are mostly incidental and not as frequent as interactions within a course of study. These findings show that repeated interactions between individuals would generate higher propensity for communicating which later give more opportunity for social learning and social influence to induce compliance in the population.





One of the elements that can be transferred from the model into real systems is behaviour insights obtained from the simulation experiment. The insights obtained in this study may be useful for understanding and finding possibilities for influencing travellers' change of behaviour during the implementation of a demand management measure in practice. For example, the simulation shows that involving 'key people' in diffusing compliance with the measure into population would increase the level of participation. It supports the importance of 'key people' involvement in promoting a soft measure, which is one of tools for changing behaviour suggested by Ampt (2003).

The model developed in this study is still limited to be able to derive any conclusions in terms of substantial 'quantitative' findings from the results. However, we may consider that the findings produced by the model is more in 'qualitative' sense than 'quantitative', since the model is used to explore or to understand causal relationships of interaction between people in real world society. Much elaboration is needed to produce sufficient sensitivity and accuracy in order to ensure that the findings are substantially important.

Finally, the model has shown how we can incorporate social aspects, such as social interaction, social learning, and social influence, into modelling travellers' decision making and behaviour. The use of an agent-based simulation model is also expected to have implications for travel behaviour modelling practice as some potential benefits can be gained from this tool.

8. FUTURE RESEARCH

The simulation experiment presented in this study is a demonstration of how we can predict the changes of travellers' behaviour when social interaction, social learning/imitation and social influence exist. The way these aspects may increase effectiveness of a 'soft' demand management measure is an informed insight obtained from this study. To make the prediction of the model more reliable, more credible parameters for the model are highly required. These can be done by conducting intensive behavioural survey and laboratory experiments in order to evaluate these parameters. More reliable parameters will give better understanding about behavioural mechanisms and causal relationships between individuals in the society. The understanding is important for developing a model which is able to represent individuals in real society as agents in the model. Hence, better qualitative understanding can be produced.

The development of a method to measure diffusion effects in the implementation of a 'soft' measure, as identified by Stopher (2005), would provide a benefit in obtaining empirical data that can be used to validate the results of the simulation model. Empirical data from a longitudinal study with several waves before and after the implementation of a 'soft' measure would serve best for validation purpose.

The concepts and model presented in the paper may be applicable to other situational contexts, with some modifications and customizations to fit with specific characteristics of





each situational context. There are also possibilities to run different kinds of scenario using the model in order to gain some informed insights for formulating and evaluating effective policy interventions.

Studies on predicting the effects of diffusion process in the implementation of 'soft' measures, such travel blending, individualized marketing, and car sharing, may benefit from this study. However, applications of the model into real-world practice still requires further development as the model is relatively simple and the factors involved in the practice would be much more complicated and beyond the scope of this study. There are also interrelationships between the social aspects with other individual aspects, such as personality, attitude, habit, etc; as well as complexity of travel environment that need to be considered in the further development.

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