Using Agent-Based Modelling for Investigating Modal Shift: The Case of University Travel

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Abstract

Travel mode choices are a result of several factors and how they affect individual travellers. This paper examines those factors influencing travellers' mode choices commuting to and from a university. Furthermore, we investigate how a shift to alternative modes can be stimulated within the current transport system environment of that university. From focus groups studies, seven measurable themes were identified as metrics for travellers' satisfaction. Descriptive data has been collected from 348 participants through questionnaires. The analysis of the questionnaires provided insights into the development of appropriate policies to stimulate travellers' mode shift. To allow for studying the impact of applying proposed interventions over time, we simulated the effects of those interventions on travellers' mode choice by using an agent-based social simulation approach. We employed a framework designed for modelling modal shift in the transport domain to build the simulation model, taking the themes into consideration. The outcomes of the study assisted in understanding how decision factors and their interconnections contribute to sub-populations of travellers' choice. In addition, our experiments helped in assessing the importance of interactions among travellers on their decision making. Such an understanding provides insight into those factors within the system that need to be considered when policymakers develop strategies for interventions for mode shift. The outcomes of the simulation experiments indicate that different policy interventions result in distinct travellers' mode adoption patterns and that interventions perform better when the right categories or groups of travellers are targeted. In addition, the intervention should focus on the right travellers' concerns and be applied in the right proportion. This social simulation study has also demonstrated how a theory-based framework can be used with survey data in numerical experiments to explore real-life scenarios for the development of actions to promote behavioural changes.

Keywords: Travellers; Modal shift; Agent-based modelling; Social simulation; Cognitive work analysis

1 Introduction

The transport sector is a complex system characterised by environmental, social, health, economic and land use challenges (Roberts et al., 2017). This is partly due to the increase in the demand for personal daily mobility needs. Experts in transport attribute most of these problems to uneven distribution in travellers' mode usage patterns (Aderamo, 2012; Chapman, 2007; Graham-Rowe et al., 2011). According to the DfT (Department for Transport) (2009) and Short (2002), private vehicles are the preferred mode, thereby contributing severely to the challenges for the transport sector. There has been an increased focus on the need for travel mode shift among travellers in recent times. The current attention can be attributed to substantial socioeconomic and health benefits that a shift in mode usage patterns can bring (Steg, 2007). Therefore, in addition to existing approaches to mitigate the challenges, behavioural change in travellers' mode choice has been suggested as a short-term solution with reduced costs (Roberts et al., 2017). A change in an individual traveller's or a group of travellers' mode choice behaviour can best be achieved by understanding the factors that influence the choice of the preferred travel mode and by providing appropriate interventions to stimulate their behaviours. Some questions that need answers in this regard are: (1) How can policymakers identify the factors within a transport system that determine travel mode choice?, (2) How can policymakers gain insights into how the factors influence travellers' behaviour given the dynamics of activities and adaptive nature of the travellers within the system?, (3) What impact do the social interactions among travellers have on their mode choice decisions?, and (4) Which policy measure or combination of policy measures would most effectively stimulate the behaviour of an individual traveller or a group of travellers towards adopting an alternative, environmentally friendlier, but less preferred travel mode?

In this paper, we present an agent-based social simulation study for travel mode choice of a set of travellers to and from a university, to answer these questions for this specific case. The study aims to investigate those factors within the university's transport environment that influence travellers' decisions regarding which mode to choose for their travels. It also examines the shift in their mode usage pattern in response to policy interventions regarding such factors as well as how the interactions among travellers influence their choices.

For the modelling, we follow a structured approach by applying the MOdal SHift (MOSH) framework (Faboya et al., 2017). The MOSH framework is an agent-based modelling framework for modelling the adaptive nature and dynamism in a sociotechnical system. It also provides support for strategic policy development within the transport environment. The MOSH framework integrates Human Factors and Psychology knowledge to model factors that influence people's behaviour in product choices that involve alternative options.

The outcome of the study contributes to our understanding of how the non-linear and interrelated decision factors evolve to determine travellers' decisions as well as the importance of interactions among travellers on their decision making. Such an understanding provides insight into factors within the system that need to be considered when policymakers develop strategies for interventions to trigger modal shift. In addition, it provides an understanding of the combination of policy measures that could effectively stimulate travellers' behaviours in mode choice.

The paper is organised as follows: Section 2 provides some general background, including an overview of the MOSH framework and related works. Section 3 describes the model development and details of the model implementation and experimentation. Section 4 presents the discussion of findings. Finally, Section 5 provides our conclusions and suggestions for future work.

2 Background

Many factors are involved in travellers' decisions regarding their preferred travel mode. Also, the activities of a traveller in various situations as the journey progresses have a dynamic character that impacts their decisions. The spatial and temporal orientations of travellers' perception of their journey make the research questions within the transport system environment more complex and dynamic. A transport environment seen as a sociotechnical system, consists of infrastructural technology as well as human beings using the infrastructures to achieve a purpose. The complexity of a sociotechnical system is due to the dynamics and adaptive nature of the human aspect of the system and its inter-related and non-linear decision factors, coupled with their interactions with other elements of the system. Furthermore, in order to achieve the aim of this paper, a framework that supports investigations into individual travellers' activities that led to mode choice such as the Agent-Based Modelling (ABM) paradigm appears to be appropriate. In this section therefore we discuss ABM and the modal shift framework used in this study.

2.1 Agent-Based Modelling

ABM is a way to model the dynamics of complex systems and complex adaptive systems behaviours (Macal & North, 2010). ABM considers a system from the perspective of the inherent agents. Agents are autonomous entities within a system that have behaviours, learn from their experiences, interact with each other and the environment, and influence each other. They are capable of changing their behaviours during the simulation in an adaptive system as they learn, encounter novel situations, or as populations adjust their composition to include a larger proportion of other agents who have successfully adapted (Macal, 2016). The heterogeneous nature of agents allows adequate representation of various demographic attributes that can be found in humans. The disaggregate behaviour of the individual agents within an environment gives rise to emergent and observable system effects.

The agent-based paradigm has proven to be a useful method to investigate an individual's behaviour in an adaptive complex system, and amongst others, it has been applied in many studies that involve human behaviour in logistics. Its application includes freight planning (Bean & Joubert, 2018), vehicle routing management (Aragao et al., 2019), passengers' behaviour in emergency evacuation (Miyoshi et al., 2012; Na & Banerjee, 2019), travel mode choice (Shukla et al., 2013), etc. In the following section, we provide an overview of the agent-based MOSH framework we used in this paper.

2.2 Overview of Modal Shift Modelling Framework

The MOSH framework works on the principle that the challenges due to travel mode usage can be perceived from the system's environment and from the travellers' behaviours. The resultant effects of individual behaviour, especially in situations where most travellers prefer a travel mode (e.g. private car) to other modes, are often felt within the environment. This situation calls for fact-finding and knowledge gathering about the problems. The collected facts are analysed with various relevant analytics techniques, including an analytical component of the MOSH framework, so as to understand the causes of the problem. The knowledge derived from the analytic processes informs the development of strategies for interventions. Furthermore, an individual traveller makes a decision on their preferred travel mode based on their previous experiences and current mental state, which are updated on the basis of a set of cognitive processes and information-seeking strategies guided by the decision module components of the MOSH framework.

The MOSH framework shown in Figure 1 consists of three basics modelling components: (1) the Socio-Technical Environment that houses the policymakers and the travellers; the resources within the environment that are available and are applicable to all travellers within the system irrespective of status, thereby making the environment the decision context of travellers (Jager et al., 2000); (2) the Agent Decision Module that is based on the Consumat approach (Jager, 2000; Jager & Janssen, 2012); (3) the policymaker module that represents the stakeholders who carry out the activities, such as knowledge gathering and uses the Cognitive Work Analysis (CWA) (Rasmussen et al., 1994; Vicente, 1999) to analyse the travellers as they traverse the system environment.

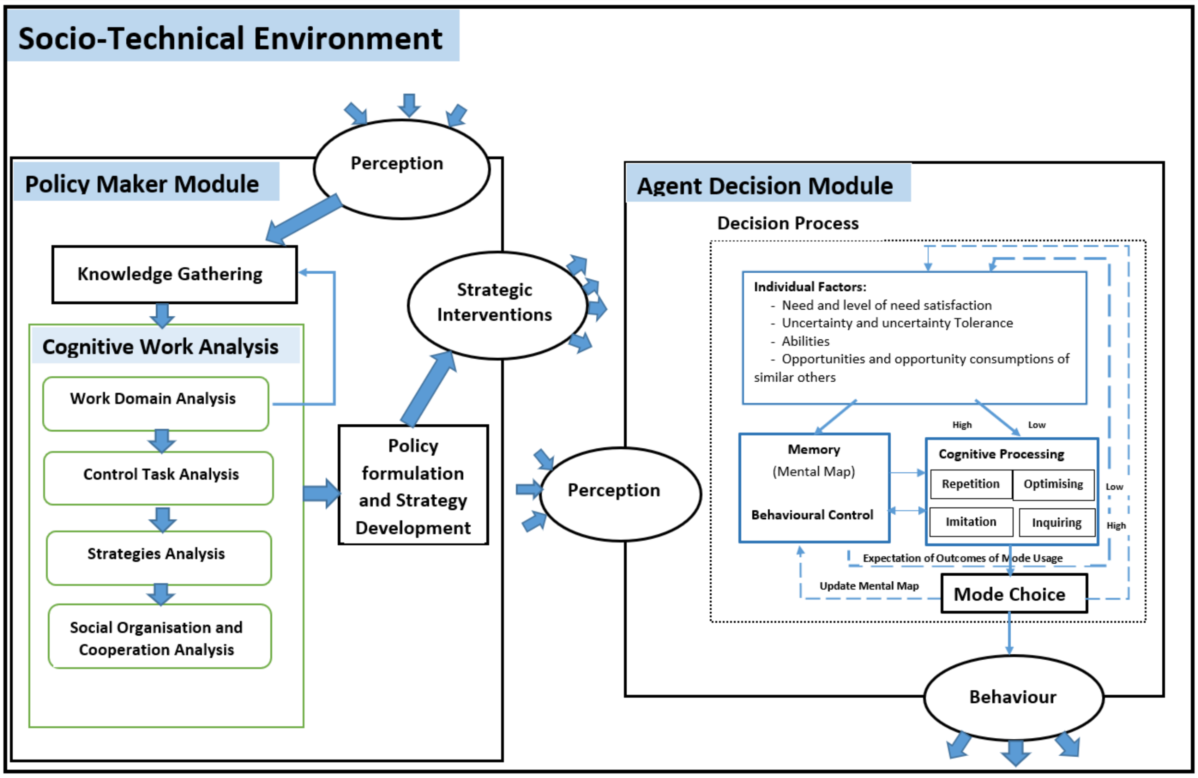

Figure 1 ***Error! No text of specified style in document.****: MOSH framework (Faboya et al., 2017)*

The MOSH framework integrates two major modelling components to achieve the modelling objectives of analysing the dynamic activities and adaptive nature of travellers within the complex transport system. The first component is the CWA component, which has four of its five analytical phases included in the MOSH framework. The four modelling phases focus on how human-system interactions could be conducted within a given domain, rather than how they currently work or how they should operate. Each phase of CWA models a different constraint set within the system. The overview of CWA phases is detailed in Naikar (2006) and Cornelissen et al. (2013). In this paper, the use of the CWA aspect of the MOSH framework is limited to the first two phases, i.e. the Work Domain Analysis (WDA), and the Control Task Analysis (ConTA).

The WDA uses the Abstraction Hierarchy (AH) to simultaneously describe constraints on the performance of actors enacted by the system's characteristics (Cornelissen et al., 2013); as well as the environment in which the activity is performed. The second phase of CWA is the Control Task Analysis (ConTA) that analyses the traveller's situation at various stages of the journey with respect to the functions that can be performed in these situations. For instance, a traveller accessing travel mode information (function) while en-route a destination (situation). ConTA models the activities with the Contextual Activity Template (CAT). The CAT analytic outcome often reveals the aspect of a traveller's behaviour where more attention is needed when developing strategies for interventions. The CWA has been used in many studies including, for example decision support systems (Effken et al., 2011); constraints exploration in rail transport (Stanton et al., 2013), military domain (Naikar et al., 2014), and variability in users behaviour (Cornelissen et al., 2013). The second major modelling component of MOSH framework is the Consumat component, which integrates several known socio-psychological theories such as motivation and personality (Maslow, 1954), development and human needs (Max-Neef, 1992), and normative, gain and hedonic (Lindenberg & Steg, 2007). The Consumat addresses the idea of some frameworks that see human actions in decision making as rational and calculative, by providing different decision strategies that range from simple habitual to a more detailed heuristic of inquiring from others within the system. Furthermore, decisions are often made under uncertainties.

The Consumat incorporates social engagements among travellers such that a traveller can interact with similar other travellers by obtaining information on their beliefs that may alleviate its own decision uncertainties. Several studies, including Kangur et al. (2017), Janssen & Jager (2001), Janssen & Jager (2003), and Jager et al. (2000), have implemented the Consumat approach.

Many ABM frameworks have been developed in order to address various aspects of agents' interactions and behaviours in a social context. In contrast to all of these, the MOSH framework focuses on providing modelling capability for analysing the adaptive and unplanned behaviour that can be found with travellers. It also provides insights into those factors influencing travellers' behaviour and how they are related. The Consumat component provides the MOSH framework with modelling capabilities for social heuristics, and possible network structures for agent interactions. It also supports the presentation of the detailed cognitive processing of human decision making that include possible interaction processes.

2.3 Related Work

Both, psychological and ergonomic factors have been identified to influence travellers' decisions in relation to their travel mode. Several works involving transport psychologists and computational modellers have been done in these aspects. These works focus on investigating the impacts of such factors on travellers' travel mode choice. For instance, Mann & Abraham (2006) and Gardner & Abraham (2007), in separate studies that involved identifying psychological factors that influence travellers behaviour, found that journey-based affect, autonomy, effort minimisation, personal space concerns etc., are common factors that influence the behaviour of travellers towards car use. Stanton et al. (2013) in their work also found that there are interrelationships between ergonomic constraints that impact on mode choice and travel decisions. In addition, some utility factors that include cost and value for money, punctuality and reliability, frequency of the mode, comfort/cleanliness, bus stop/interchange/station facilities, etc. have been identified in several studies including Derek Halden Consultancy (2003) and DfT (2012) as major factors in travellers mode choice.

Furthermore, the modelling for computational mode choice studies have mostly relied on mathematical modelling techniques. For instance, Sakano & Benjamin (2011) used a structural equations model to examine commuters' planning decision about activities and modes. The study revealed that commuters' mode choices are effected by their activities at the destination. Nurdden et al. (2007) identified demographic variables such as age, gender, car ownership, etc. as major factors that prevent personal transport users from utilising public transport in Malaysia. They used a binary logit model for their studies. Atasoy et al. (2012) used structural equation and traditional mathematical discrete choice models respectively to show that attitudinal variables present significant contributions to mode choice. Other studies include Osman Idris et al. (2015) and Tudela et al. (2011) that integrate human psychological factors and habits into a hybrid discrete choice model to model mode choice. Roberts et al. (2017) in their study combined traditional discrete choice models with a structural equation to model commuting mode choices, and Temme et al. (2007) used a hybrid method for their studies that involve classic choice model and structural equations to model mode choices. There are some disaggregate models, among which is Heath & Gifford (2002) who used the theory of planned behaviour to model factors that determine travel mode choices of travellers in Malaysia. The behavioural architecture used in their study is based on a single socio-psychological theory of human behaviour, which can be considered to be inadequate to represent human behaviour in a complex transport system. Nevertheless, there are few available modal shift studies and the ones that exists mostly focused on freight and shipping transports (e.g. Islam et al., 2016; Blauwens et al*.,* 2006).

In all the studies reviewed, it can be observed that: (1) Most available travel mode choice models are centred on the *modal split*, which looks at the proportion of passengers using a particular travel mode. Such models are not behavioural, and they often employ an aggregate approach to produce results. Therefore, they could be good for planners and engineers who are interested in making predictions about future (Barff et al., 1982), but are inadequate for policymakers who wish to understand the motives behind travellers' mode choices, so as to intervene. In view of this, a behavioural modelling approach that incorporates human behaviour theories and allows an investigation of individual travellers' behaviours is appropriate; (2) The majority of the work that attempt to investigate factors that influence the decisions in travellers employ mathematical modelling techniques (Osman Idris *et al*. 2015; Tudela *et al*. 2011; Domarchi et al., 2008; Atasoy et al., 2012; Temme et al., 2007). With the level of complexity found in transport systems, investigation or decision making relying on mathematical modelling methods would be difficult to achieve and error-prone. Such approaches impose limitations on the models' capabilities and limit the application of many relevant theories of human behaviour in choice making. Moreover, attempts to include many traveller attributes in mathematical modelling result in multiple complex equations due to interrelationship that exists among them; hence, the results could be difficult for non-experts to comprehend. More importantly, social interaction structures that exist among travellers and their immediate environments are not emphasised or explained in the methodologies provided by these models. Lastly, real-time and dynamic observations of travellers' behaviours are not possible due to the static nature of the mathematical approaches. To address these limitations, an ABM approach is explored in this paper, and its capabilities are demonstrated with the help of a case study.

3 Case Study

The case study described in this paper involves a set of travellers to and from a university. The set of travellers include different categories of people, such as academics, full-time students, part-time students, managers, etc. The perception is that there is currently a rise in the number of travellers using a car to travel to and from university, which has been identified from resource usage, e.g. parking space availability. The purpose of this study is therefore to investigate how interventions can stimulate people's mode choice to change from car usage to other, more environmental friendly travel modes, available within the university scenario. In our case study, a university traveller can choose from the following travel modes: public transport, bicycle, walking, and use of private car.

3.1 Data Collection

The procedures for data collection and analysis are detailed in Faboya et al. (2018)[1]. The study investigates the impact of travel requirements i.e. physical, cognitive and affective considerations on individual travellers' satisfaction without recourse to social interactions among travellers.

In this paper, we provide an overview of the data collection and analysis process relevant to the study presented. The data collection procedures involves focus group sessions where travel mode concepts are identified. Those include: (1) the needs that a traveller wishes to satisfy; (2) the travel mode aspects that are required to achieve the needs, and (3) the constraints to achieving the needs.

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[1] The work involved focus groups meeting discussions, collection of descriptive data through questionnaires, and the generation of individual travellers' physical, cognitive and affective perceptions (i.e. travel requirements) from the survey data. The CWA together with relevant statistical methods were used in the analysis. The study adopted Monte Carlos modelling techniques to determine how travellers' considerations for travel requirements in planning for journeys impact on their needs satisfaction. The work described there differs from the work described in this paper as follows: (1) the questionnaire information only provides a descriptive view at specific points in time and do not permit to capture the dynamics of a system over time, therefore, focusing on individuals while excluding the impact of interactions among travellers on their decisions, and (2) to allow studying the impact of applying interventions over time, we modelled the effect of interventions on travellers' mode choice by using an agent-based social simulation approach.

Travellers' needs include *efficiency*, *safety* and *comfort* regarding the journey to and from the university. The *efficiency need* defines the traveller's wish to enjoy low travel cost and time-efficient transport systems. The *safety need* relates to making journeys with the possibility of no incidences or reduced incidents. Finally, the *comfort need* focuses on the flexibility in journey control and availability of general transport environment's facilities.

The identified travel mode's aspects are the same as the ones identified in Stanton et al. (2013), these are defined to represent a set of related travel mode attributes. The travel mode concepts are *information provision, timeliness, reliability, frequency, speed, security, safety, autonomy and privacy, control over journey* and *protection from bad weather*. These are also used as measure of performance for each travel mode later in the study. In addition, a questionnaire is used in the data collection process. The questionnaire items includes intuitive questions tailored towards mode-related scenarios, so as to ensure neutrality in both, the affect and the utility measures of the attribute investigated (Steg, 2005). The questions focus on the travel modes' attributes that are of concerns to the travellers. The attributes are *ease of accessing information, reliability of available information, ease of getting to destination on time, ease of getting on and off the mode, parking space concerns, delays, security en-route the university, safety en-route the university, availability of road signs, attitude of other road users and protection from weather elements*.

The validation and reviews of the questions for the questionnaire were made by experts in Human Factors and Transport Operations. The feedback resulted in several iterations of the questionnaire. The final version can be found in Appendix 1. In the end we jointly reached the conclusion that the questionnaire was fit for purpose.

There are two sections in the questionnaire, one focussing on demographics and one focusing on travel mode perception. The demographics part collects participants' responses on the basic information such as age, sex, occupation etc.; the travel mode perception section consists of Likert scale and open-ended questions. Each Likert scale questions requires two responses, the first response answers *"how satisfied*", and the second answers *"how important"* the travel mode concept under consideration is to the respondents. The two responses are needed to generate individual traveller affectivity regarding each of the investigated travel mode attributes. The questionnaire was administered online and through physical distribution of a printed form to enable sufficient data collection and more extensive representation among respondents within the university community.

Participants in the study include:

- 82 cyclists, 37 females and 45 males, aged between 20 and 56 years.
- 81 personal car users, 46 female and 34 males, aged between 18 and 63 years.
- 93 public transport users, 46 female and 47 males, aged between 16 and 45 years.
- 92 pedestrians, 31 female and 59 males, aged between 18 and 63 years, and two that preferred not to declare their gender.

In the next section we describe the link between the data gathered through the questionnaire and the parameterisation of the simulation model agents.

3.2 Data Analysis

Table 1 shows the relationship that exists between the travel mode attributes, the defined travel modes' concepts, the criteria for performance evaluation and the functional purpose of the travel mode. The description of the columns of Table 1 are as follows: Column 1 contains the considered travel mode-specific attributes (e.g. *ease of accessing information*) on which survey data is sought. Each travel mode attribute is related to one or more elements in column 2. Column 2 contains the defined travel modes' main concepts selected for investigation among the transport system's areas that have been identified as the sources of concerns to travellers. The selected concepts are those that are relevant to the achievement of the study's aims, but not the transport environment's resources in their entirety. Column 3 contains the criteria for performance evaluation, which measure how well the travel mode is satisfying the needs of the travellers on each of the items in column 2. Column 4 contains the travel mode's functional purpose consisting of the three needs of the travellers on their journey to and from the university as identified during the focus group discussions (efficiency, comfort and safety).

Table 1: Travel mode's attributes, concepts, and functional purpose relationships table

Subject of investigation Items in the questionnaire	Travel mode concepts related to subject of investigation	Criteria for performance evaluation	Functional Purpose
-Ease of accessing Information. -Reliability of available information. -Ease of getting to destination on time. -Ease of getting to main travel mode. -Getting On and Off the mode. -Distance to the main mode.	Information Provision Timeliness of the travel mode Reliability of the travel mode Speed of the travel mode Frequency of the travel mode	Journey Time Reliability Cost and Value for Money	**Efficient**
-Parking Space concern. -Delays. -Security en-route the mode. -Safety on the main mode.	Physical Ability Security Safety	Security Comfort	**Safe**
-Availability of Road signs. -Attitude of other road users. -Walking from main mode to destination. -Protection from weather.	Protection from Poor Weather Autonomy/Privacy/Journey Control	Convenience Personal Mobility	**Comfortable**

To better understand how to read Table 1, we provide some examples. If we focus on the relation between travel mode concepts (column 2) and criteria for performance evaluation (column 3), we can see that *information provision*, *timeliness*, *travel mode reliability, speed* and *frequency of travel* are used for making judgements about a travel mode's *journey time* performance. If we focus on the relation between criteria for performance evaluation (column 3) and functional purpose (column 4), we can see that the performance metrics such as *journey time, reliability*, and *costs and values for money* are all used for making judgements about travel mode efficiency. The content and the relationships shown in the table assisted in the construction of the AH which will be discussed in the next section.

3.2.1 The Study's Abstraction Hierarchy

The resources within the transport system environment and the information provided in Table 1 are used in the construction of the AH shown in Figure 2.

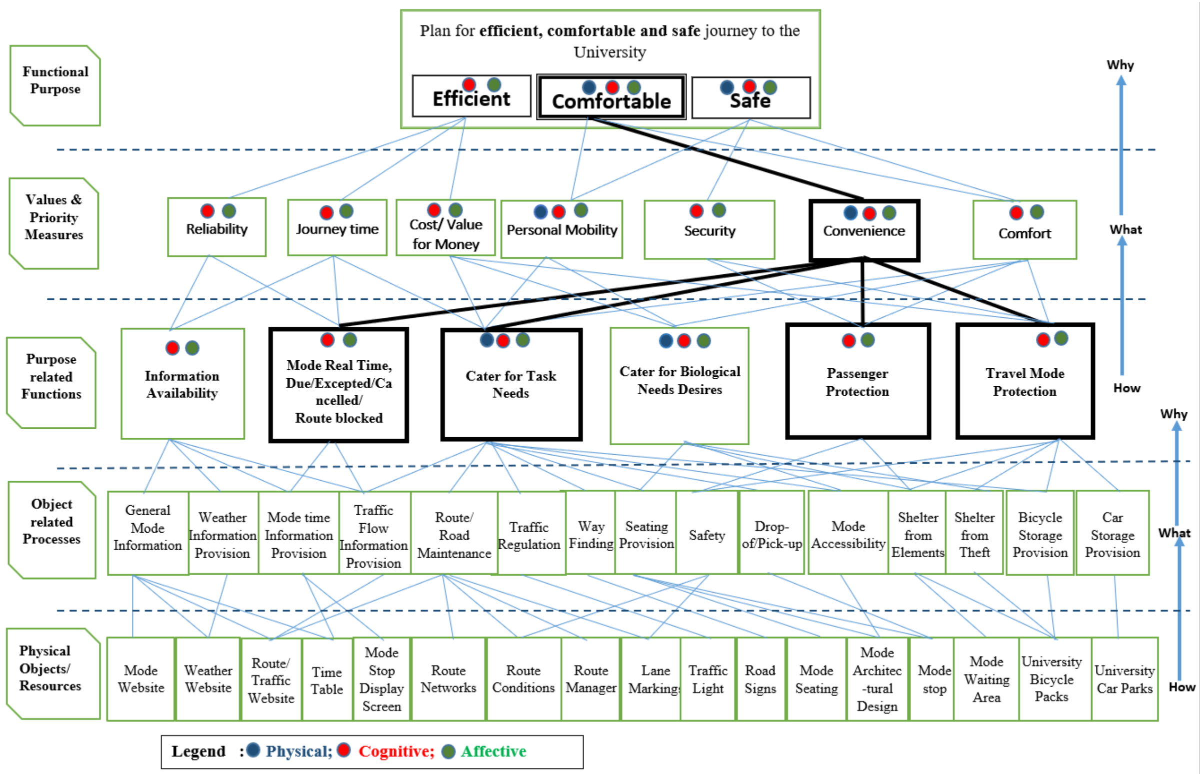


Figure 2: The Abstraction Hierarchy for travel mode's environment with Indications of physical, cognitive and affective considerations

Here, our focus is on the influence of travel mode's attributes on the three needs of a traveller (efficiency, comfort, and safety). An *efficient* transport system has a direct link to cost savings (e.g. lower fuel consumption), reliability and time to destination. Traveller's need for *comfort* includes the flexibility in journey control, privacy and autonomy, good seating provisions and accessibility for disability, etc. Finally, the travellers' *safety* has links to a secured, healthy and convenient environment; safe walkways for pedestrian, clearly marked lanes for the cyclist, traffic light and road signs, and security at all times.

Each of the *functional purposes* (i.e. traveller's needs) and *values and priority measures* (i.e. the criteria for performance measure) nodes has an indication of two or three different colours. These colours indicate the level of physical, cognitive and/or affective (PCA) involvement for each box that contributed to the mode choice decision. The PCA factors are among the travel requirements (Wardman et al., 2001) believed to impact on mode choice. The blue, red and green colours represent considerations for the PCA aspect at the nodes respectively (Faboya et al., 2018).

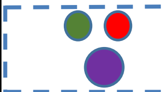
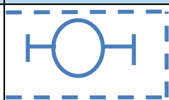
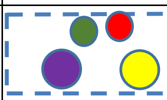
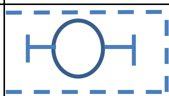
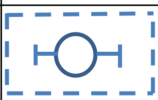
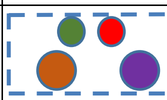
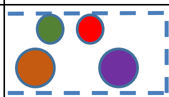
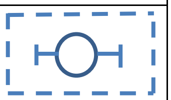
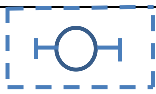
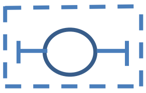
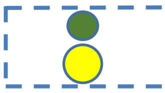
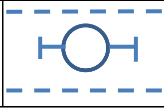
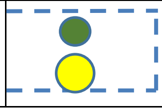
The AH is constructed using its natural AH *'how-what-why'* triads. As an example for how we create these triads, let's focus on the highlighted nodes and means-ends links in Figure 2: If *convenience* node is taken as the '*what*' at the *values and priority measures level,* the means-end links connecting this node up to the higher levels of abstraction show that it can support the provision of *comfortable journey* at the *functional purpose* level of the system. That is, it can be seen that *convenience (what)* occurs to ensure that *comfortable (i.e. the 'why')* is provided in the system. To show how the *convenience* node ('*what*') has been derived, the boxes below the *convenience* indicate that it is supported by the *travel mode protection, passenger protection, cater for biological needs desires, cater for task needs and mode real-time (i.e. the 'how')*. The same process is used to form the rest of the links in the AH.

3.2.2 Construction of Contextual Activity Template

The CAT used in this study is adapted from the Stanton et al. (2013)'s rail passenger study. A CAT is a two-dimensional table that presents situations at the horizontal axis and the functions a traveller can perform in each situation at the vertical axis. Six identifiable situations of a traveller's journey to and from the university are modelled, and presented in Table 2. As specified in the original CWA (Naikar et al., 2006), the situations at the horizontal axis of the table are segmented according to the time and space of the recurring schedule. The identified travellers' situations are origin/destination; en-route to mode stop; at the mode stop; en-route to the university; at the university parking/ storage facilities, and en-route to the destination. The *origin and the destination* are included under one heading as the role are interchangeable. The destination for one journey is often the origin of the next, therefore functions should apply equally to both (Stanton, 2013). *En-route to the mode stop* and *at the mode stop* applies to public transport users moving from an origin to the bus stop. The *en-route to the university* includes when a traveller is on the travel mode to the university *and en-route to the destination* is the transit from the mode stop, car park or cycle shed to the final destination (office or lecture room) within the university. The *university parking/storage facilities* include situations when a traveller is at the university's parking facilities in the case of car users and cyclist. The functions considered for modelling in this paper are taken from the object-related processes of the AH (see Figure 2); these are represented at the vertical axis of the table.

Due to space constraints, only the CAT that represents cyclists activities on their journey to the university is shown in Table 2. Circles without solid fill indicate the functions that can be perform at various situations and the boxes around each of these circles indicate all the situations in which this function can occur.

Table 2: CAT representing Cyclists population with Efficiency, Comfortability and Safety consideration (adapted from Stanton et al., 2013)

Situations / Functions	Origin/ Destination	En-route to Mode Stop	At the Mode Stop	En-route to the university	At the University Parking/ Storage facilities	En-route to destination
Shelter from elements						
Shelter from Unsavoury persons						
General mode information						
Travel mode (Cycle) routes						
Way Finding						
Personal safety						

The bars within each box indicate those situations in which the function typically occur (Naikar et al., 2006). The functions that a cyclist might wish to perform to satisfy its needs at various situations during the journey include *shelter from elements* (e.g. rain, snow), *shelter from theft* which is applicable to both the cycle and cyclists. Others are *general mode information* (e.g. checking weather information or information about obstructions due to construction works); *cycle route conditions*; *wayfinding*; and *personal safety*. Circles with solid fill appear in two sizes. The smaller ones represent the PCA considerations when performing a function as earlier mentioned in Figure 2. For instance, row 1 of the CAT has s*helter from elements* as a function; the presence of two smaller coloured circles *green* and *red* indicates that affective and cognitive aspects are considered by the cyclists at the *En-route to the university* situation. The bigger brown, purple, and yellow circles represent travellers' needs of *efficiency, comfort* and *safety* (ECS) respectively. The presence of any of these colours in a node indicates that the traveller's need represented by that colour is affected by the ability or inability of the traveller to perform the function in that situation. In the case of the previous example (i.e. shelter from elements), the bigger purple circle indictae that traveller's comfort need is affected by the ability or inability of the function to occur.

Furthermore, considering our example on the function *shelter from elements* across all situations, our interests are on: (1) what level of cognition is required to locate a suitable and safe shelter (if any) as the cyclist is cycling en-route to the university, (2) is there any physical effort required to achieve the objective, and (3) is there emotional effects of having a system that provides resources to satisfy or otherwise the need of protection from elements (i.e. affective consideration). The possibility (or ease) of carrying out a function or not at a given situation has an impact on the travellers' needs of efficiency or comfort or safety. Tracing through the *shelter from elements* function in Table 2, it can be seen that *origin/destination* and *at the university parking storage* situations support the function, that is, the function can naturally occur under these situations. In the situation *en route to the university*, the function could occur, but typically does not (expressed by showing the dashed box only) with the indications of cognitive and affective components. The cognitive and affective indications show that generally in bad weather such a rainy or snowing, a cyclist may have the need to stop-over for a while.

The absence of such resources at these situations will impacts on the traveller's comfort only, while *shelter from theft* impacts on the safety and comfort. The rest of the CAT are constructed following the same rules.

3.3 Development of Policy Interventions

The AH in Figure 2 and the CAT analysis in Table 2 assist in identifying the needs of an individual traveller or a group of travellers, as well as the travel mode's attributes that supports the achievement of the needs. The information supports the development of strategies to influence travellers' behaviours. These strategies are developed around the seven metrics earlier identified (and listed in Table 1) for measuring the travel mode performance. Each category of traveller has different concerns; therefore various suggestions are made on how to address the constraints imposed on them by the transport environment as well as the constraints inhibiting their shift to other travel modes. Table 3 summarises the areas of concerns of different categories of travellers.

Table 3: Travellers areas of mode concerns

Concerns / Travellers	Comfort	Personal Mobility	Reliability	Safety/Security	Cost and Value for money	Convenience	Journey Time
Pedestrian	Protection from elements.	Route maintenance.	-	The attitude of other road users; inadequate road signs in some areas.	-	-	Set out earlier than expected.
Cyclist	Protection from elements.	Cycle lane obstruction; unmaintained lanes during winter.	-	The attitude of other road users; road signs and route maintenance.	-	Cycle shed locations and sufficiency.	Delays: route obstructions and traffics.
Public transport user	Protection from elements at some bus stops currently lacking.	-	Ease of accessing information; reliability of provided information.	Attitude of some bus users.	Reduced fare.	Distance to mode stop, ease of getting to mode stop.	Delays: timeliness and frequency of bus.
Car user	-	-	Inadequate traffic flow information.	-	High parking fee.	Limited parking space; distance from the destination.	Traffic jam at peak hour

Based on the concerns as well as suggested solutions expressed by different categories of travellers, strategies are developed and policies are formulated for interventions. For instance, among the suggested solutions for cyclists are: *campaigns and awareness for other road users to respect cyclists as equal road user; imposition of fines for obstructing cycle lanes; proper cycle lane maintenance especially during winter; creation of dedicated cycle lanes; availability of more parking spaces and cycle sheds; building shelters along the cycle lanes*, etc. It can be observed that all suggested solutions for cyclists are centred around five values and priority measures: *comfort personal mobility*, *safety/security, convenience and journey time.* For the public transport users' concerns, the following solutions are suggested: seating provision and protection from elements at the bus stop where currently not available; offline information access and improvement in the current bus reliability regarding advertised schedule; measures be put in place regarding the unpleasant attitude of some public transport users; reduction in travel fares to university; provision of local link buses to ease access to the bus main stops in environments that are far from main bus stops; buses to the university be made more frequent than the current operations to reduce journey time associated with delays. Pedestrians are more concerned about *comfort* due to protection from elements, hindrances regarding their *personal mobility, safety/security* due to other road users' attitude as well as reliable weather information. Lastly, the car users are unhappy with the high parking fee and parking spaces far away from their destination within the university.

3.4 Model development

3.4.1 Model conceptualisation

The conceptual diagram in Figure 3 is an adaptation of the MOSH framework diagram presented in Figure 1. It provides a conceptual overview of the case study by capturing the daily decision processes and activities of a traveller to and from the university.

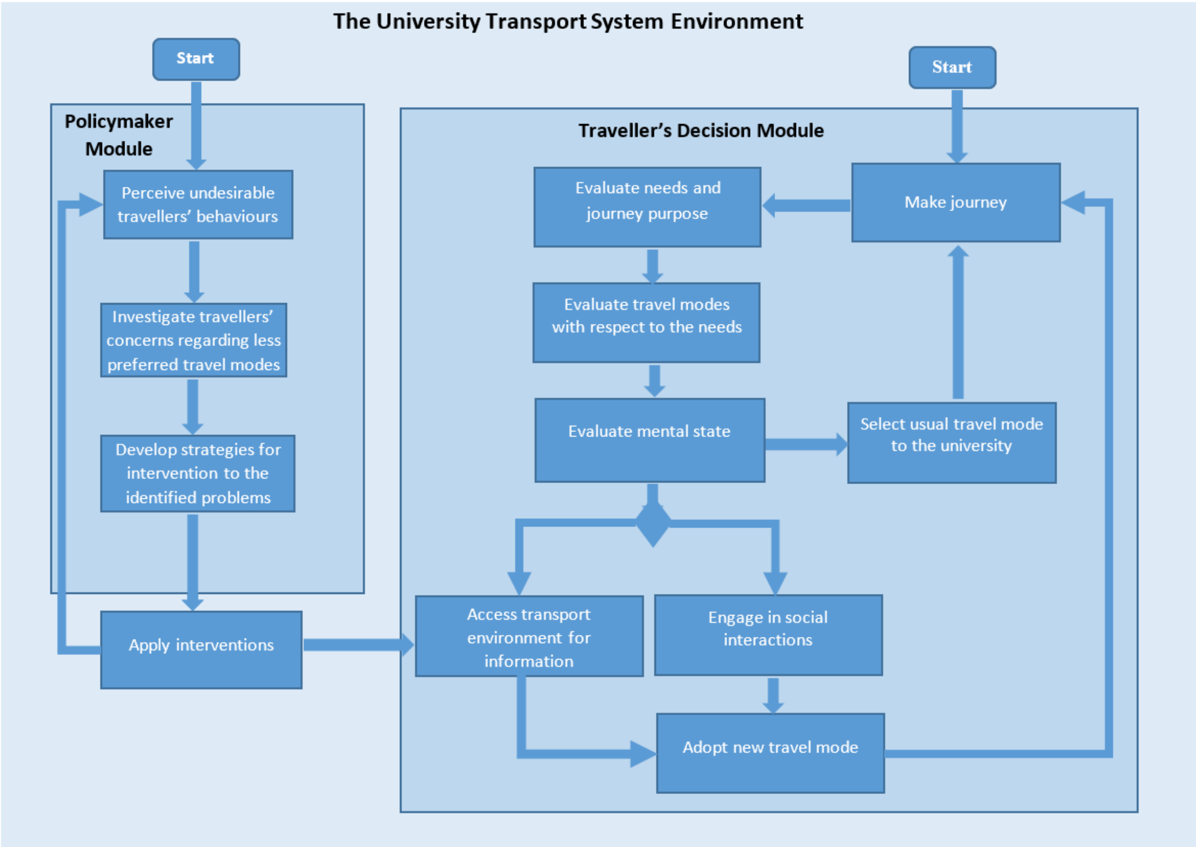


Figure 3: Conceptual Diagram of the system

As depicted in Figure 3 by the boxes and arrows combination on the right, a traveller plans to make a journey to the university by first evaluate it needs and the purpose of the journey. The traveller then considers the available travel modes with respect to those needs, this evaluation is based on their previous experience regarding the travel modes. The result of this evaluation updates the traveller's mental state, which reflects its level of *satisfaction* and *certainty* regarding the travel mode. It then chooses among the travel modes, based on the level of certainty and satisfaction regarding the modes, under the condition that the travel modes are accessible (e.g. by ownership, cost affordability). The mental evaluation process that includes the information-seeking strategies is detailed in Section 3.4.2. A traveller's mental state status determines the kind of cognitive processing to engage in, in order to increase knowledge of other travel modes in the environment, if dissatisfied or uncertain.

The policymakers (the boxes/arrows combination in the left of Figure 3) including the university transport management, the county, and the transport companies, have the responsibility of investigating the causes of perceived unpleasant situations observed in the environment. The policymakers then formulate policies and develop strategies from the knowledge gained from the investigation. The policies and strategies are provided as interventions to be applied to the university transport system environment to stimulate travellers to the adopt alternative travel modes.

In our model, the following assumptions are made: (1) the likelihood of a traveller to invest into a new travel mode such as buying a bicycle or car for the purpose of making a journey is not considered, and (2) all travellers have the abilities for the travel requirements (i.e. PCA considerations) to make use of their usual (i.e. preferred) travel mode. In the model, the following simplification is made: travellers always make use of the chosen travel mode to and from the university.

3.4.2 Information Seeking Strategies

The activity diagram in Figure 4 represents a travellers' mental state evaluation process. The traveller's mental state is its current state, which indicates whether the traveller perceives itself as *satisfied* or *unsatisfied* and as *certain* or *uncertain*.

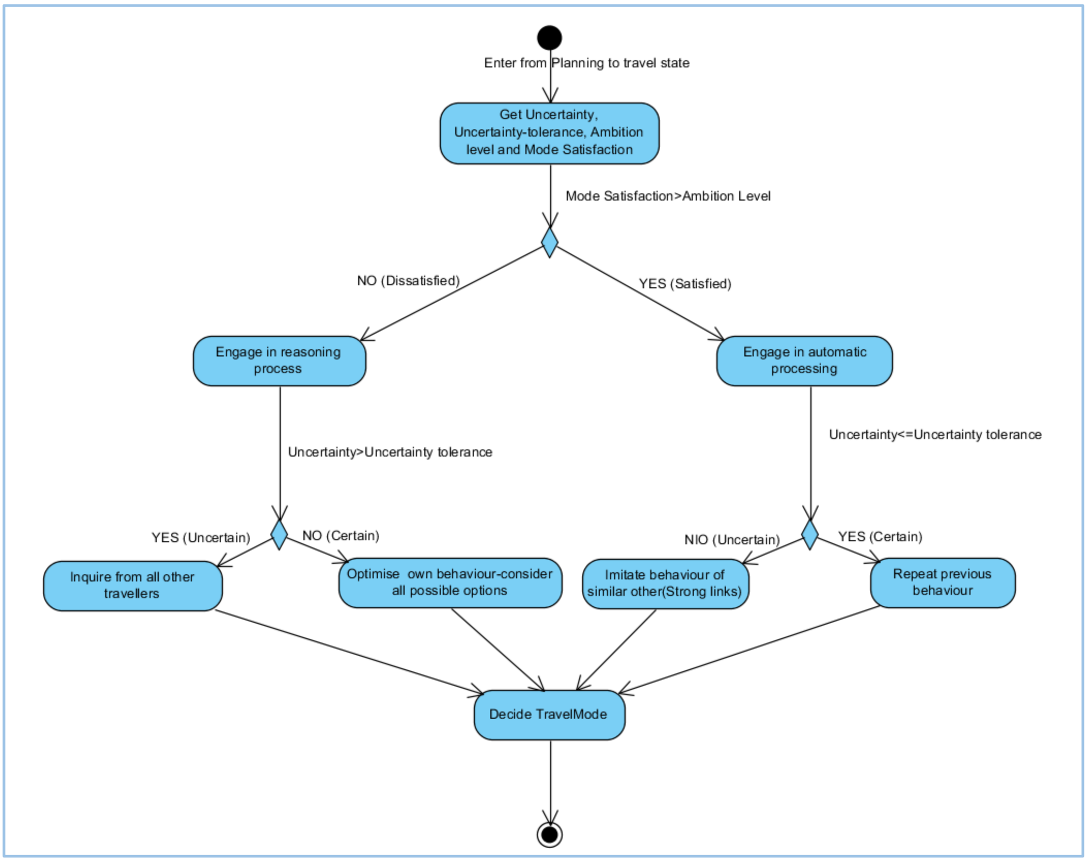


Figure 4: Traveller's mental state activity Diagram

After the traveller has evaluated its mental state, it decides about which information-seeking strategy to select. The four main features that drive a traveller's decision in this respect are: the *ambition level*, *uncertainty state*, *uncertainty tolerance,* and the *satisfaction level*.

The four information-seeking strategies that are available to the traveller mirror the agents' cognitive processes in the original Consumat framework (Jager, 2000). In general, an unsatisfied state results in a search for new information, while a state of being uncertain (with the travel mode) causes travellers to explore what other travellers do to make their journeys. When the traveller is *satisfied* and *certain* with its current travel mode, it *repeats* the current behaviour without checking on another travel mode. A *satisfied* and *uncertain* traveller engage in social comparison to *imitate* (a form of social interaction) the behaviour of other similar travellers. These travellers are the ones that the initial traveller has strong links with. When the traveller is unsatisfied but certain, it optimises its own knowledge by seeking new information within the environment through adverts, interventions, etc. When a traveller is unsatisfied and uncertain, it seeks new information by *inquiring* (a form of social interaction) from others about their travel modes.

In summary, a traveller can engage in the following four processes: (1) *individual processing* (i.e. repetition and optimising) when the level of uncertainty is low, (2) s*ocial processing* (i.e. imitation and inquiring) when the level of uncertainty is high, (3) *Automatic processing* without reasoning when the travel mode satisfies the needs of the traveller (e.g. repetition and imitation), and (4) *Reasoning processing* when the traveller is dissatisfied with the travel mode (e.g. optimising and inquiring). The choice of travel mode for the journey is based on the dynamics of the four factors. The information-seeking process (if successful), leads to the adoption of a new travel mode.

3.4.3 Model Implementation

The model was implemented in the Recursive Porous Agent Simulation Toolkit (REPAST), a Java-based simulation toolkit for ABM (https://repast.github.io). The model is available as "MOSH University Travel Simulation Model" from https://www.comses.net/. For details about the implementation, please refer to this resource.

3.4.4 Parameterisation

We initialise the variables inside the simulation model with empirical data from our survey. The four travel modes considered possess specific concepts on which travellers' views are sought as listed in Table 1. The intervener is a stakeholder that develops and applies interventions to stimulate travellers' mode choice behaviour. The traveller is the main active object in the simulation with various attributes; hence, the following describes traveller's initialisation in the simulation.

Based on the original data collected, all the 348 traveller agents are equipped with demographic details, personal characteristics as well as their initial preferred travel mode, previous experience, mode ownership status and uncertainty tolerance.

In terms of demographics, each traveller agent has a gender, age, designation (the status) within the university, disability status, average daily distance covered, frequency of mode usage, preferred travel mode, etc. In terms of personality, each traveller agent has needs, including ECS. These needs are the purpose of using the travel mode for getting to/from the university. They attach varying levels of importance to the various aspects of their travel mode needs; this forms their ambition regarding the needs. For instance, a safety-conscious traveller attaches higher values to issues related to safety while deliberating on its travel modes. Such importance often reflects on the traveller's level of ambition (i.e. satisfaction tolerance). This also translates to the weight attached to such a need (i.e. needs weight). A traveller weighs its needs concerning various purposes as well as the social needs used for interactions within the networks of friends. Together all these parameters determine the traveller's mental state and overall satisfaction as expressed below:

(i) Traveller's *ambition* is the quantity used to express what level of needs satisfaction a traveller wishes to experience (satisfaction tolerance). This is the mean of all attributes of a travel mode that link to the need in question. It is evaluated on each of the three traveller needs as shown in Equation 3.1.

$$Needs\_ambition = \sum_1^n \frac{attribute\_importance}{n} \quad (3.1)$$

Where:

$attribute\_importance$ is the traveller's perception (survey value) on how important a travel mode attribute is. Following the means-end links in the AH (Figure 2), one or more attributes contributed to a need. n is the numbers of attributes used in the evaluation.

(ii) The *needs weight* is the normalised *importance* values for the three needs of a traveller indexed between 0 and 1. Hence, the weight that traveller agent a attaches to a need i is given by Equation 3.2.

$$Needs\_Weight_i = \frac{Needs\_ambition}{\sum_1^n Needs\_ambition} \qquad 3.2$$

Where:

$Needs\_ambition_i$ is the ambition value for traveller's need i; and $\sum_i^n Needs\ \_ambition$ is the ambition values for the set of needs considered. For instance, the *efficiency-need-weight equals efficiency-ambition/(total value of all needs importance)*. The respective weight is used to factor the traveller's experience satisfaction and uncertainty in the overall satisfaction.

(iii) The traveller needs are the travel mode's *efficiency* (i.e. in term of cost, speed, etc.), *comfort* and *safety* that individuals mainly need to balance when considering their preferred travel mode. Hence, the traveller's three needs satisfaction is derived from the survey data as the mean of their satisfaction perception of all travel mode attribute linked to the need i (see Figure 2) as shown in Equation 3.3.

$$Needs\_Satisfaction_i = \sum_1^n \frac{(attribute\_satisfaction)}{n} \qquad 3.3$$

Where:

$Needs\_Satisfaction_i$ is a traveller's level of satisfaction ineed i; and $attribute\_satisfaction$ is the satisfaction perception on all travel mode's attributes related to the need i.

(iv) A traveller's *overall satisfaction* is derived from the *needs satisfaction* and their associated *weights* following the Cobb-Douglas utility function derivatives shown in Equation 3.4.

$$overall\_satisfaction = Need\_satisfaction_{(1)}^{Need\_weight_{(1)}} X \dots X Need\_satisfaction_{(n)}^{Need\_weight_{(n)}} \qquad 3.4$$

Where:

$Need\_satisfaction$ is the level of satisfaction for each of the traveller's needs i; $Need\_weight$ is the corresponding weight a traveller attach to need i; needs i = 1…n.

The reason for using the utility function's Law of Constant Returns to Scale is to have an output that will be proportional to the changes in inputs factors, which will also factor the resulting overall satisfaction level to a number between 0 (minimum) and 1 (maximum).

(v) As explained in the original Consumat (Jager, 2000), the social weights of a traveller are evaluated from its social needs that consist of three aspects: conformity, anti-conformity, and superiority. Conformity drives a traveller to adopt similar behaviour to those around it, anti-conformity obtains the direct opposite, i.e. being unique and therefore showing different behaviour than others. The superiority aspect reflects the traits of being superior to others in the network. For instance, a traveller who owns an elegant car may feel socially superior to someone riding a bicycle. Every traveller places a different emphasis on these three components of their social needs by using a different set of social weights. In this paper, the social needs are derived from the similarity that exists among travellers within a network regarding their attributes such as *occupation*, *travel mode type*, *usual distance range*, *mode ownership,* etc. The more similar two travellers are in their mode usage regarding these attributes, the greater the influence they have on each other's social satisfaction.

(vi) Uncertainty in traveller's decision arises from previous mode usage experiences. The failed expectations when compare the past and present experiences are the sources of uncertainty used in the simulation as shown in Equation 3.5.

$$Uncertainty_t = Overall\ Satisfaction_t < Overall\ Satisfaction_{t-1} \quad 3.5$$

Where:

$Uncertainty_t$ is the level of uncertainty at t, $Overall\ Satisfaction_t$ is the overall level of needs satisfaction at time t, and $Overall\ Satisafction_{t-1}$ is the overall level of needs satisfaction at time t -1.

Moreover, each traveller has a different tolerance level as a threshold to individual traveller's uncertainty. In this study, the travellers' uncertainty tolerance levels could not be initialised using the survey data. Hence, a Gaussian random sample is drawn for each of the travellers at the moment of initialisation to represent the uncertainty tolerance. However, the effect of using random samples is observed on the model's behaviour by varying the random sample value and adjusting it to reflect the real-life behaviour of the travellers. Each traveller agent starts the simulation with a preferred travel mode. Travellers' previous experience is set to zero at the beginning of each simulation run.

3.4.5 Validation

Several validation and verification techniques suggested by Law (2008) were used to ensure the credibility of our simulation model. Firstly, we verified that the model is programmed correctly, and the algorithms are implemented appropriately. Secondly, experts in relevant disciplines such as Human Factors transport research and ABM were consulted to validate the model. They reviewed the questions at the data collection stage to ensure relevant data is collected, and also reviewed the conceptual model on which the simulation is based, to ensure that it represents the real world with sufficient accuracy for the purpose at hand. In addition, the model validity was also tested through observing various outputs generated from the simulation. As part of the validation process, a confidence interval approach using paired-t hypotheses testing (Law & Kelton, 1991) was used for a pair of travellers' parameter: *satisfaction/ambition.* The hypotheses employed and the outcome are summarised in Table 4. The test confirms (as the p-value is larger than the α value) that travellers are satisfied when the satisfaction is smaller or equal to their ambition level.

Table 4: Hypothesis Testing: Satisfaction-Ambition level

Null hypothesis	H_o: Travellers are *satisfied* when their satisfaction level <= their ambition level.
Alternative hypothesis	H_a: Travellers are satisfied when their satisfaction level is > their ambition level.
Population of travellers	600
t	3.1114
df	599
p-value	0.999
Confidence interval	0.95
α	0.05

3.5 Experimentation

3.5.1 Design of Experiment

In the experimentation section, we look into the base scenario and two policy interventions scenarios. The experimental factors (i.e. the settings that vary between scenarios) are: (a) the demographics of the population, (b) ratio between prefered travellers populatio, (c) ratio between stereotype gropus, (d) initial prefer travel mode, and (e) policy choice to stimulate travellers' behaviour. The responses (i.e. the outputs) observed during the simulation runs are:

a. travellers' average daily satisfaction.
b. travellers' mode shift diffusion pattern
c. travellers' cognitive processing pattern
d. travellers' average needs satisfaction regarding their travel mode.

The simulation model runtime is set to 365 (representing 365 days). We conduct 20 replications to account for randomness in the parameterisation process. A warm-up period of 5 days is considered to remove initialisation bias.

3.5.2 Base Scenario

The base scenario represents the scenario for the calibration of the simulation model with survey data. It also serves as the basis against which the impact of the policy interventions is compared. The responses observed during the simulation runs are presented in the following sub sections.

Travellers' average daily satisfaction

Figure 5 shows the default average daily satisfaction of travellers for all the travel modes considered. In the figure, there is an early steady state which is a direct representation of the real-life average satisfaction in the population of travellers. The graph indicates that the car user category is 70.0% (in average) satisfied, which makes them more satisfied than other categories of travellers. The public transport category has 69.0% average daily satisfaction, and the cyclist group has 65.5% average daily satisfaction, respectively. The pedestrians with 62.8% average daily satisfaction are the least satisfied among the categories of travellers, which is a reflection of the current situation among the travellers to/from the university.

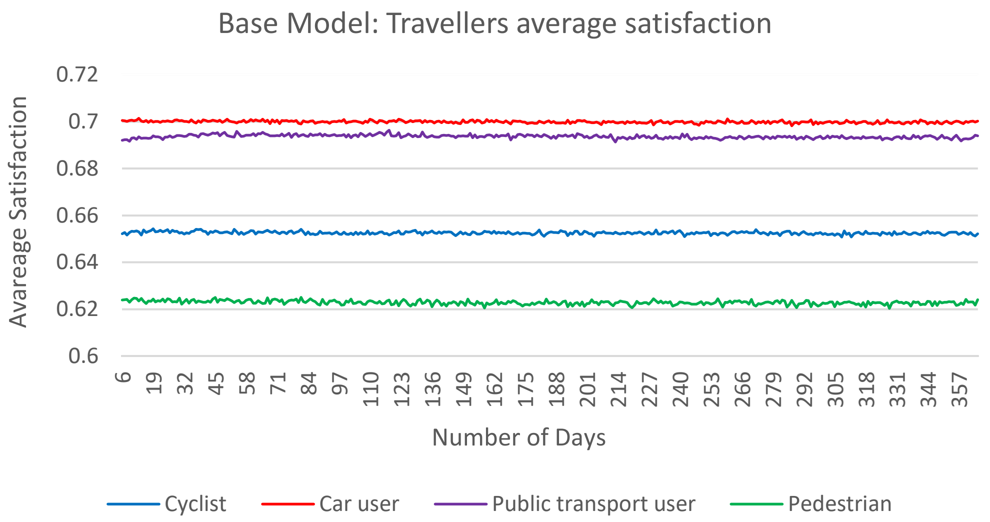


Figure 5: Base scenario travellers' average daily mode satisfaction

Travellers' mode shift diffusion pattern

Figure 6 presents the travel mode shift pattern among travellers. The university transport system that our simulation represents is an operational system. Our simulation starts with an empty system; therefore, we observe a point where the aggregate number in each category of travellers appear steady. In the graph the travellers' travel mode adoption pattern become relatively stable after day 70, which is then selected as the intervention point (during experimentation).

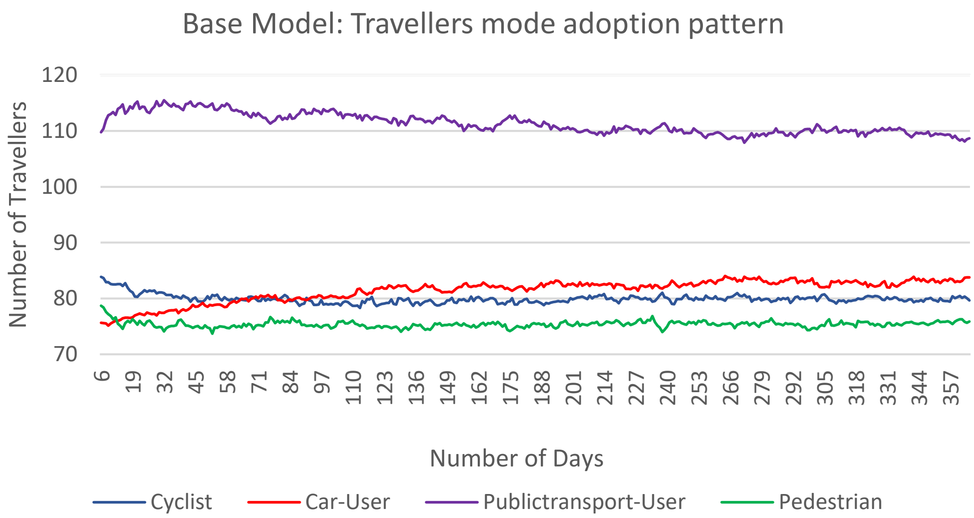


Figure 6: Base scenario travellers' mode shift pattern

In the figure, the number of pedestrians reduced from the initial setup value of 79 travellers to 75; while the number of car users settles at 84 after the initial drop to 75. There is an initial increase in the number of cyclists to 84 before it finally settles at 80; the public transport users' number increases from the initial set up value of 93 to 115 but remains stable at 110. The observed changes in the numbers of various categories of travellers can be attributed to their interactions during information seeking process on how others make decisions on satisfying travel mode.

In particular, the observed increase in the number of public transport users can be attributed to a considerable shift from pedestrians. However, the shift indicates that there are underlying factors that keep public transport sufficiently attractive to pedestrians but not to other travel modes. For instance, one reason that prevents pedestrians from shifting mode to cycling includes safety. It is noted that the dissatisfied group from both pedestrian and cyclist populations consists of those who are concerned about safety due to the behaviour of other users. Pedestrians see public transport as a safer mode than cycling. And travellers who have access to personal vehicles adopted this mode which is the reason for a rise in the number of car users. Another reason is mode ownership; dissatisfied pedestrians might not have access to a bicycle or a private car. However, more insights are examined by looking into the cognitive processes engagement by the travellers in seeking information that enables them to choose suitable travel mode.

Travellers' cognitive processing

Figure 7 presents the travellers' cognitive processing for the base scenario. As explained in Section 3.4.2, a traveller can engage in any of the four information-seeking strategies while making a decision of the travel mode to choose. Figure 7 indicates that 280 travellers are engaging in individual cognitive processing, comprising of 170 travellers *repeating* and 110 *optimising* their behaviours.

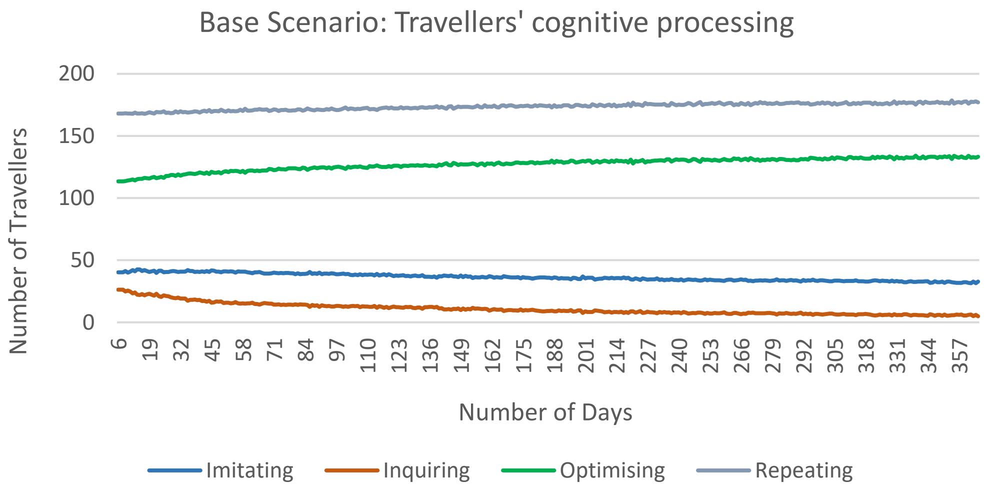


Figure 7: Base scenario travellers cognitive processing

The high number of individual processing reflects the level of satisfaction expressed among travellers (see Figure 5), which is between 63.0% and 70.0%. When travellers are satisfied, they engage in individual thinking rather than in social interactions. The remaining 68 travellers involved in social interactions include those that are uncertain about their travel mode. Among the social interactors are 40 travellers who are *imitating* their neighbours. This group are satisfied but uncertain about their travel mode. The remaining 28 engaged in *inquiring* from other travel mode users, these set of travellers are both uncertain and dissatisfied with their current travel mode. It can be observed from Figure 7 that, as the simulation progresses, the number of travellers engaging in social interactions reduces. This is as result of more travellers becoming satisfied. The effect can also be observed in the increase in the number of travellers *repeating* and *optimising* their behaviours.

Travellers' average needs satisfaction regarding their travel mode

Figures 8-11 present the travellers' average daily satisfaction on each of their three needs (efficiency, comfort and safety). Figures 8 and 9 represent pedestrians and cyclists' average daily perceptions while Figures 10 and 11 represent car users and public transport users average daily perceptions regarding efficiency, comfort and safety satisfaction.

In Figure 8, pedestrians show relatively average satisfaction in all their three needs. They are more satisfied with the safety aspect of walking than its efficiency and comfort. They generally rate the comfort derived from walking lower than safety. This is a reflection of the pedestrians' perceptions as captured in the survey data. The proportion of dissatisfied pedestrians in one or more aspects of walking to the university is 47.8%. Among this group, only 10.4% of this proportion consider the availability of road signs and the attitude of other road users as concerns. 62.8% of the dissatisfied pedestrian population perceive the comfort aspect particularly regarding unfavourable weather, as one of the concerns; this has contributed to the lower average of comfort satisfaction found among pedestrians.

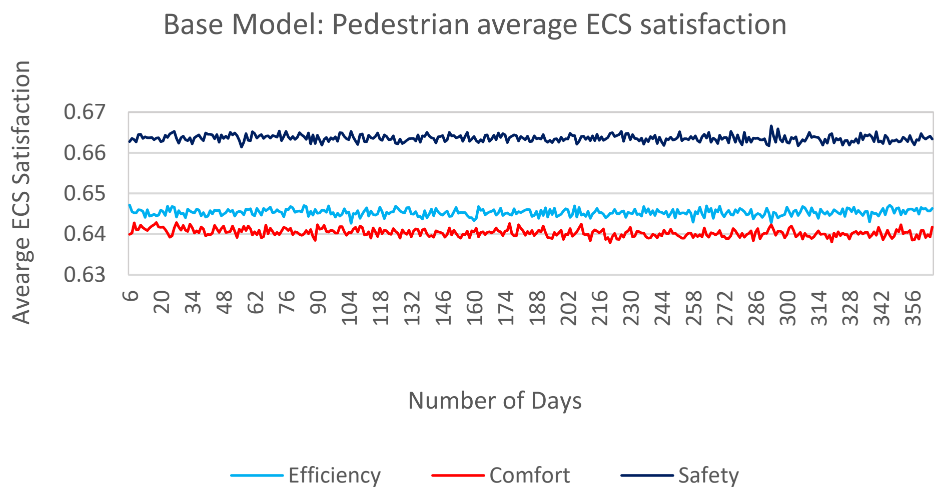


Figure 8: Pedestrian base scenario average ECS satisfaction

In Figure 9 we can see that cyclists also have a relatively high average satisfaction regarding their three needs. They are happy with the efficiency followed by the comfort aspect of cycling. Furthermore, the time series is a reflection of the current perceptions of the overall population of cyclists. The proportion of dissatisfied cyclists in one or more aspects of walking to the university is 54.9%. The high average daily efficient satisfaction can be attributed to limited delays experienced in travel time as well as low costs of cycling (e.g. no fuel consumption and free parking sheds). The survey shows that only 15.0% of dissatisfied cyclists are concerned about delays due to traffic lights and route obstructions. These coupled with the cost efficiency of cycling account for the level of efficiency satisfaction. The average daily comfort satisfaction follows closely; only 17.7% of dissatisfied cyclists are unhappy about protection from bad weather, which is the main source of cyclists' concerns for comfort. Furthermore, the cyclists' average safety satisfaction, is lower compared to the other two needs. This can be attributed to a number of factors such as the attitude of other road users to cyclists, obstruction of cycle lanes, lack of marked lane etc., which are the main areas of cycling that are associated with safety (see Figure 2). As a result, 60.0% of the total dissatisfied cyclists are unhappy with one or more of these factors in the cycling environments. The numbers account for the low average safety satisfaction found among cyclist when compared to average efficiency and comfort satisfaction.

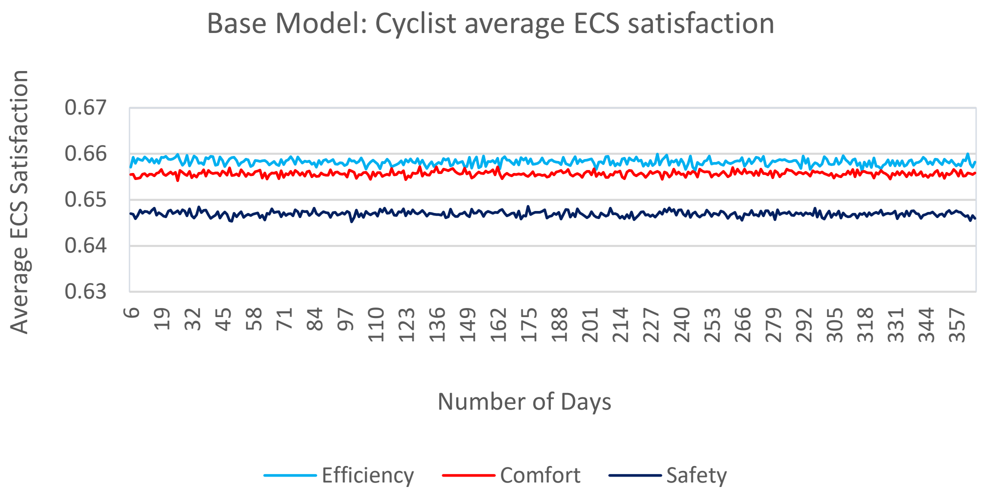


Figure 9: Cyclist base scenario average ECS satisfaction

In Figure 10 we can see how car users have high average satisfaction on their three needs with 88% average satisfaction on comfort, 86.0% satisfaction on safety, and 82.0% satisfaction of the perceived efficiency of car usage. The figure corresponds to the survey data, which indicates that car users perceived their three needs satisfactory. However, the difference in average satisfaction recorded on efficiency compared to comfort and safety can be attributed to the costs of running car modes. As shown in the survey, 19.0% of dissatisfied car users are worried about the high parking fee within the university coupled with the costs of maintaining their cars. 4.7% of dissatisfied car users are concerned about the bad driving habits of some road users.

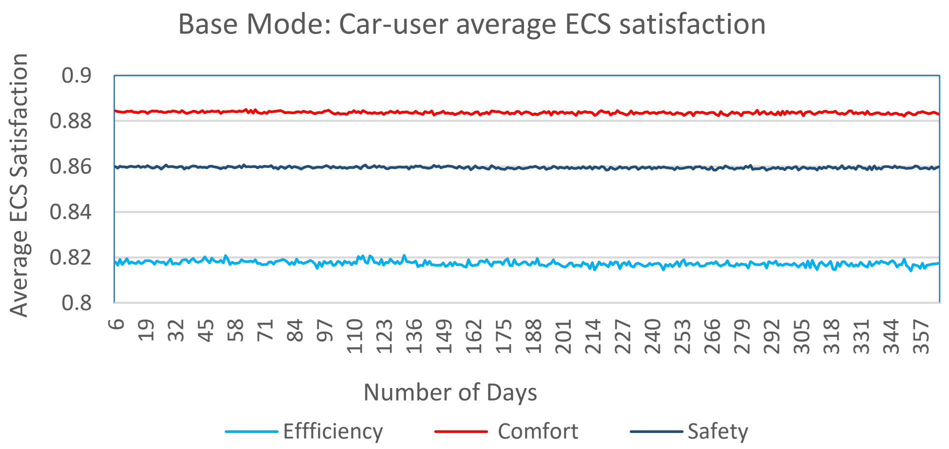


Figure 10: Car-user base scenario average ECS satisfaction

Figure 11 shows public transport users' average satisfaction on their three needs. The figure indicates that 88.0% of public transport users have average daily comfort satisfaction of 88.0 %, with average daily safety satisfaction of 85.0%, and 82.0% average satisfaction on the efficiency of the mode. The dissatisfaction represented in mode comfort can be attributed to the 12.7% of the public transport users who are concerned about comfort-related aspects of their journey such as protection from weather and getting on and off the mode. Regarding safety, 16.3% of dissatisfied users mentioned issues related to safety while on the mode and at the mode stops as part of their concerns. When compared to comfort and safety, the low average satisfaction recorded in the public transport efficiency is due to 20.1% of the dissatisfied users that are worried about delays as a result of bus frequency and frequent stopover at bus stops.

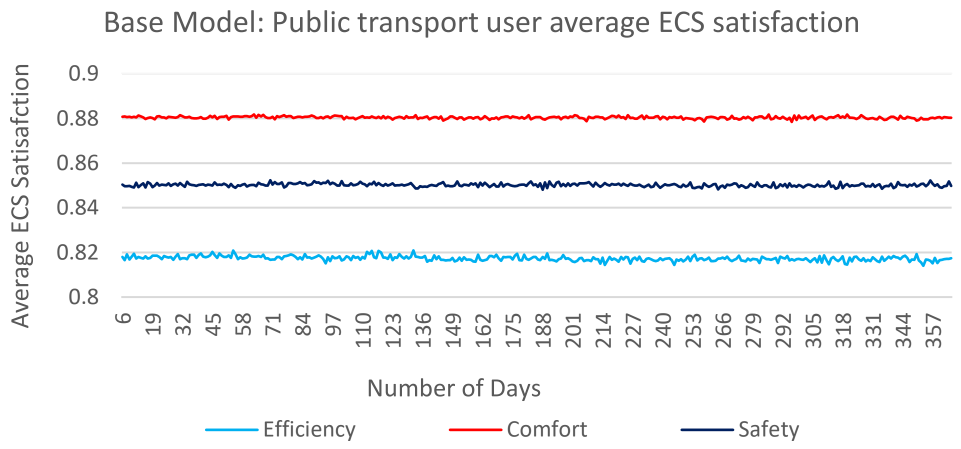


Figure 11: Public transport-user base scenario average ECS satisfaction

3.5.3 Policy Interventions

The strategies to address travellers' concerns are grouped under seven themes (as presented in Table 3). These themes are: *comfort, personal mobility, reliability, safety and security, cost and value for money, convenience*, and *journey time*. In the first set of policy interventions experiments, each of the themes is tested in a single policy regime, on each of the three travellers' categories (pedestrian, cyclists and public transport users) and their behaviours are observed. In the second set of policy intervention experiments, we looked at combined interventions that include all themes defined regarding a group of travellers' concerns.

However, due to space constraints, only the detailed analysis and graphical display of interventions related to the comfort theme are presented here. The comfort theme is chosen because it is a common concern expressed by all the travellers, even though they provided different reasons for it. The summary of our observations on the modal shift pattern of the remaining single interventions is presented in Table 6.

3.5.3.1 Single policy intervention set of experiment results

For detailed result of the first set of experiments, only the travellers' concern regarding comfort are considered. Table 5 presents the interventions selected from the policy formulation development table (Table 3) provided in Section 3.3. In the end an overview of all results is presented as a summary in Table 6.

Table 5: Individual policy intervention table for improving travellers' comfort

Concerns / **Travellers**	**Comfort**
Pedestrian	Make crossing facilities closer to each other; Re-configure traffic light to give priority; Shelter along the routes
Cyclist	Priority for cyclists at junctions; Bigger shelter along cycle lanes; Traffic lights be configured to give way to cyclist during bad weather
Public transport users	Bus stops should be provided where there is currently none and bigger ones be added.

Figures 12-19 present the adoption pattern and cognitive processing in response to comfort theme intervention for all categories of travellers. The red line in the figures indicates the point in time when the intervention is applied.

Cyclists and pedestrians mode shift adoption pattern with comfort intervention

Figures 12 and 13 present the cyclist and pedestrian mode shift adoption pattern in response to the comfort policy intervention respectively.

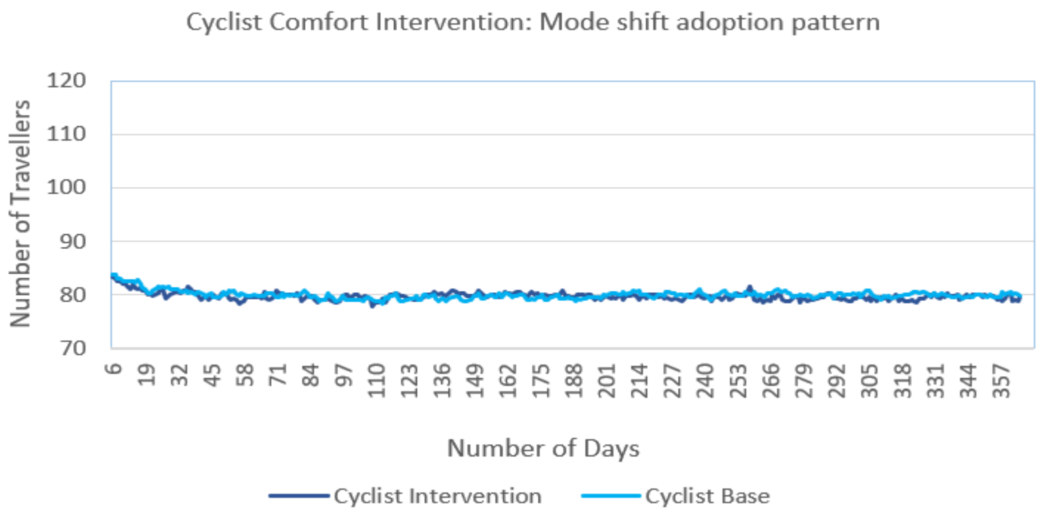


Figure 12: Cyclist comfort intervention adoption pattern

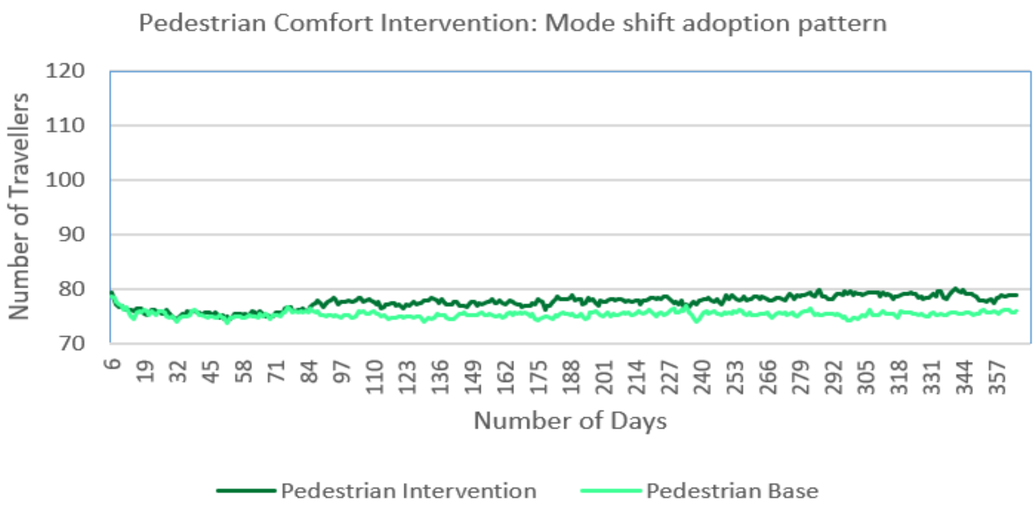


Figure 13: Pedestrian comfort intervention adoption pattern

In the explanation of mode shift adoption pattern in response to comfort policy intervention, it is worthwhile to state that the values used in the discussion are from the data analysis described in our previous work (Faboya *et al.*, 2018). In Figure12, there are no observable changes in the mode shift behaviour of cyclists with the same unit of intervention as others. Although, 17.7% of dissatisfied cyclists (i.e. 54.9% of the total population of cyclists) are concerned about the comfort due to protection from elements, which is the main source of discomfort for the cyclist. The mode shift pattern in Figure 12 indicates that intervening in cyclists' comfort concerns (e.g. priority for cyclist at junctions during bad weather) leaving other areas does not make a significant difference in their mode usage pattern. Hence, inclusive interventions that involve most of the cyclists' suggested solutions (Table 5) would attract more travellers.

Figure 13 shows the mode shift behaviour of pedestrians. It can be observed from the figure that there is an increase of 4.67% in the number of pedestrians after the intervention. This is due to 47.8% of the total pedestrians' population that is concerned in one or other areas of walking to the university, among which 68.2% of dissatisfied pedestrians are specifically not happy with the protection from elements. Therefore, interventions such as traffic light configured to give priority for cyclist and pedestrians at junctions during bad weather have impact on pedestrian behaviour, as shown in Figure 13. However, constraints such as protection from the weather for cyclist and pedestrians could be hard to remove. Better results could be achieved if such hard constraints are approached by applying suggested travellers' solutions. For instance, building shelters along the cycle lanes and walking paths for protections.

Cyclists and pedestrians cognitive processing in response to comfort intervention

Figure 14 and Figure 15 represent cyclists and the pedestrians' cognitive processing in response to comfort intervention, respectively. The time series in the two graphs show that travellers engage in all the four cognitive processes (i.e. repeating, optimising, imitating and inquiring) in both cases. However, the two graphs differ in the travellers' engagements in the cognitive processing.

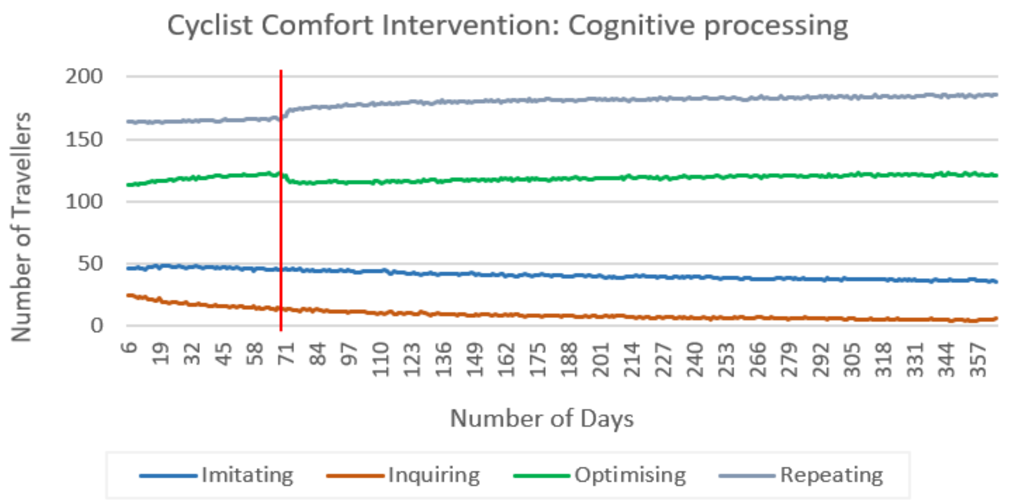


Figure 14: Cyclist comfort intervention cognitive processing

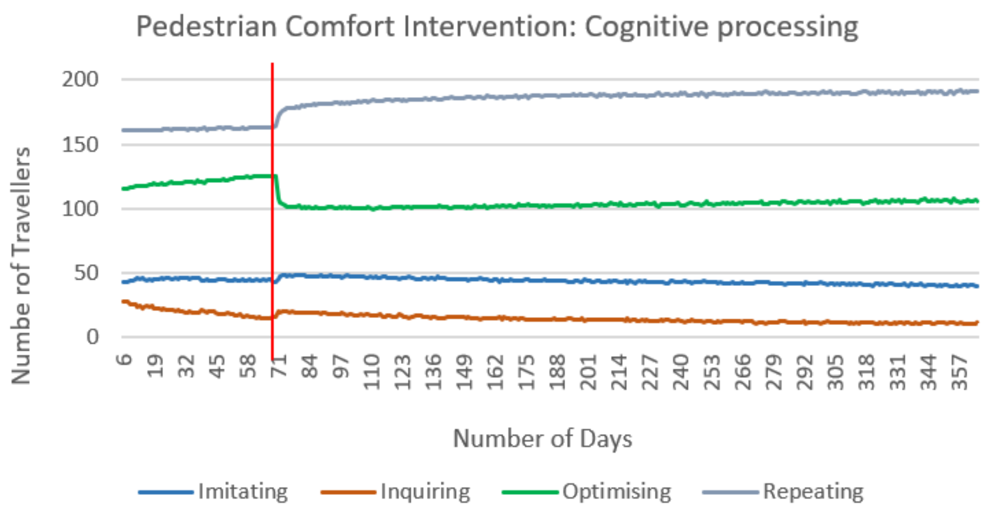


Figure 15: Pedestrian comfort intervention cognitive processing

The behaviours in Figure 14 are generally stable in all the strategies without significant changes after the intervention. The increase of individuals repeating their behaviour is a result of reductions in those optimising due to intervention and those few potential cyclists who are convinced about cycling through social interactions. The initial decrease in the number of travellers engaged in optimising is due to satisfied cyclists who are initially uncertain on various aspects of cycling to the university. The optimising behaviour is seen to be stable with marginal increase as a result of some among the uncertain group who later become more certain about cycling. However, relating the cyclists' population cognitive behaviours to their mode adoption pattern (see Figure 12), it can be observed that the impact gained regarding marginal increase in those repeating their behaviour did not transform to increase in cycling adoption pattern. Although there could be a rise in individual average satisfaction of regular cyclist, it could be that the level of comfort intervention applied is not enough to change potential cyclists who had engaged in social interactions with regular cyclists to shift mode to cycle.

Figure 15 presents a slightly different time series, which include a steady and consistent rise in the numbers of travellers repeating their behaviour, a reduction and the stable number of those engaging in optimising, and an initial increase in the numbers of those involved in social interaction. The social interactions engagements reduce as the simulation progresses due to fewer travellers who are interested in finding out about how to resolve comfort challenges regarding walking. This implies that the remaining number of travellers are not likely to change their mode regarding comfort intervention for walking. Also, relating the pedestrian population's cognitive behaviours to their mode adoption pattern (see Figure 13), the impact of the comfort intervention can be seen in both, the pattern of behaviour and the increase in the number of travellers who have adopted walking as travel mode. It can be observed that pedestrian responded better to comfort intervention than the cyclist group. However, further investigation in this regard will be helpful to determine if the total number of populations of each group in the simulation could be a factor in their information seeking strategies.

Public transport user and car user's mode shift adoption pattern with comfort intervention

Figures 16 and 17 present shifts that occur in public transport user and the car user groups with comfort interventions, respectively.

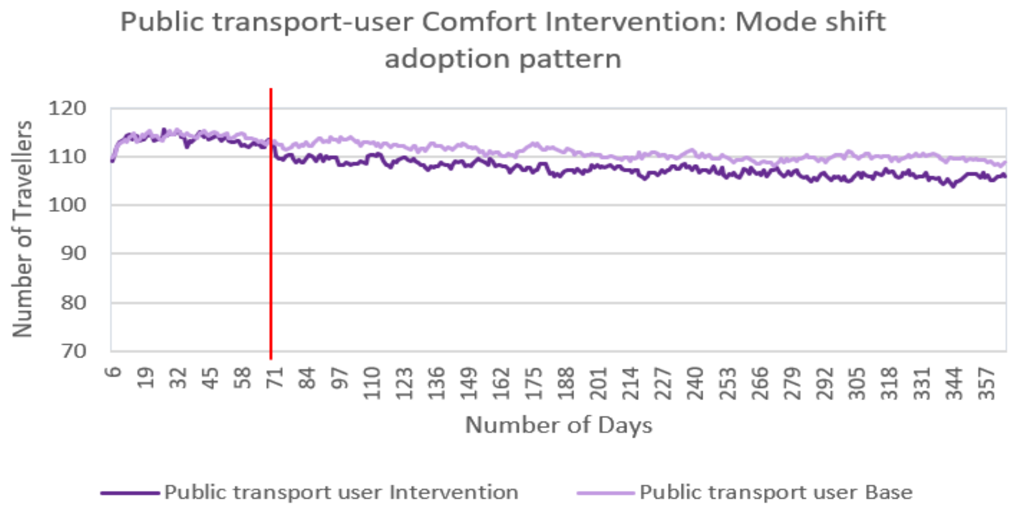


Figure 16: Public transport user comfort intervention adoption pattern

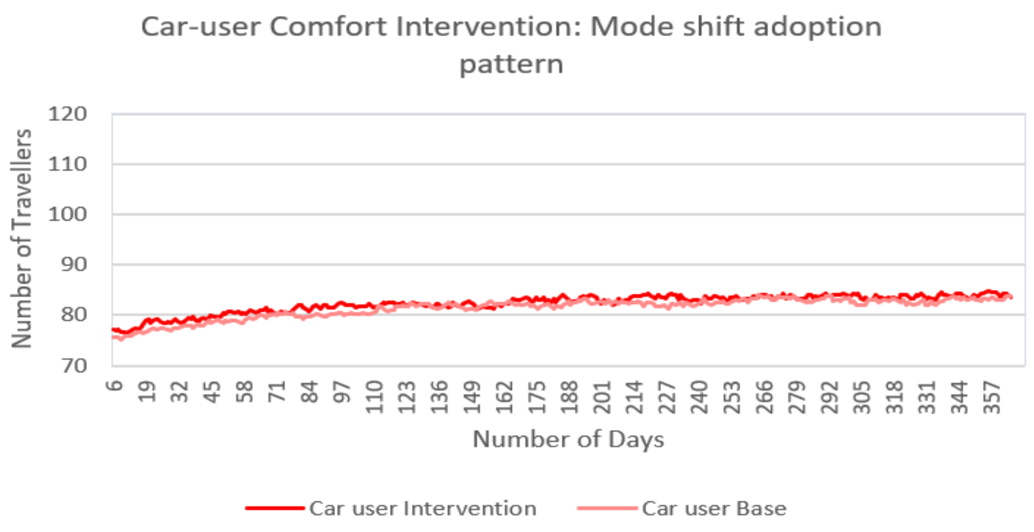


Figure 17: Car user comfort intervention adoption pattern

Our Figure 16 shows that there is a reduction of 4.7% in the number of public transport users after the intervention is applied. The shift is observed to come from the pedestrian group (see Figure 6). This explains that with interventions provided for pedestrian comforts, some public transport users prefer walking to the university probably to save them transport fare or to engage in daily exercise. Another insight from the behaviour is that most of the public users are likely living within walking distance to the university; hence, they might not travel by bus if the walking environments can be improved.

The results in Figure 17 represent the pattern of behaviour of car users. As the policy comfort intervention is not applied to the private car users (see Table 3), there is no significant observable pattern of behaviour different from the base scenario.

Public transport user and car user cognitive processing in response to comfort intervention

Figures 18 and 19 present the cognitive processes for public transport users and car users in response to comfort policy intervention.

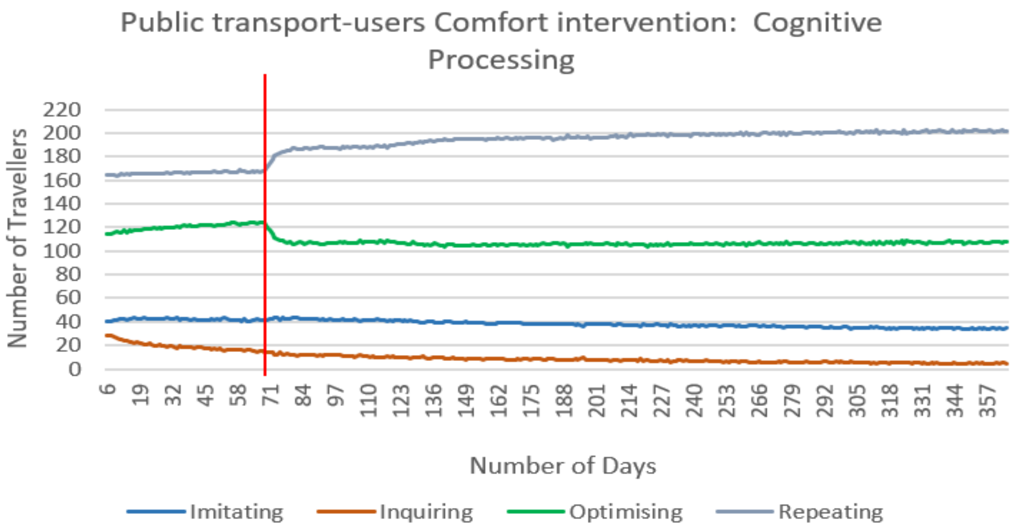


Figure 18: Public transport user comfort intervention cognitive processing

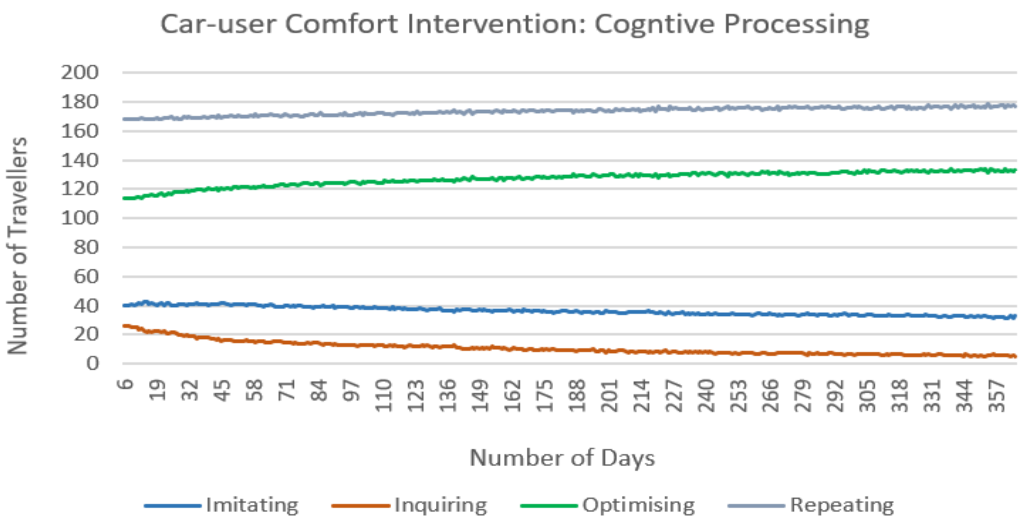


Figure 19: Car user comfort intervention processing

In Figure 18, there is a steady and consistent rise in the numbers of travellers repeating their behaviour due to comfort intervention policy applied to public transport users. Also, a stable time series regarding those engaging in optimising can be observed after the intervention. There are also observable changes in the number of travellers engaging in social interactions (imitating and inquiring) which become stable as the simulation progresses due to fewer people engagements. Relating the public transport user population's cognitive behaviours to their mode adoption pattern (see Figure 16). The impact of the comfort intervention can be seen in both the information-seeking processes (i.e. increasing number of travellers repeating their previous behaviour) and the increase in the number of travellers who have adopted public transport as travel mode. It can be said that public transport users responded to comfort intervention strategies which include the provision of bus stops where there are currently not available.

The results in Figure 19 represent the cognitive processes for car users. As with Figure 17, there is no significant observable pattern different from the base scenario, as no intervention is applied.

Summary of overall experimental results

Table 5 shows a summary of the observable behaviour of each category of travellers in response to individual interventions. From the presentation in the table, it was observed that the effect of a single policy on travellers' behaviour depends on the category of traveller and whether they have access to a travel mode (e.g. bicycle) or not. For instance, improvements in the reliability of information do not present any observable deviation in the behaviour of car users, pedestrian and cyclist from the base scenario, but do show a noticeable increase in the number of public transport users. The reason can be attributed to the proportion of travellers who are dissatisfied about their travel time to the university in each group. Also, the impact of interactions did not result to shift in mode, although this could be due to some fundamental factors related to personality. The proportion is low in other travel modes compared to public transport. Another insight is that the travel modes' attributes on which a group of travellers expressed concerns about might not pose a major challenge to their using the travel mode. In such situation, travellers are not motivated to engage in interaction and resolve to individual cognitive process (e.g. optimising). One important insight from such a scenario is that efforts and funds for interventions could be targeted at areas where much impact is recorded.

Table 6: Summary of observations on single policy interventions

	Reliability	**Journey time**	**Personal mobility**	**Safety and Security**	**Convenience**	**Comfort**
Cyclist	No observable shift in mode adoption pattern.	A slight observable shift in mode adoption pattern.	A slight observable shift in mode adoption pattern.	An observable shift in mode adoption pattern.	An observable shift in mode adoption pattern.	No observable shift in mode adoption pattern.
Public transport user	An observable shift in mode adoption pattern.	An observable shift in mode adoption pattern.	No observable shift in mode adoption pattern	A slight observable shift in mode adoption pattern.	No observable shift in mode adoption pattern.	An Observable shift in mode adoption pattern.
Pedestrian	No observable shift in mode adoption pattern	No observable shift in mode adoption pattern.	A slight observable shift in mode adoption pattern	An observable shift in mode adoption pattern.	An observable shift in mode adoption pattern.	An observable shift in mode adoption pattern.
Car user	-	-	-	-	-	-

3.5.3.2 Combined policies intervention set of experiments results

For the second set of experiments, the seven strategic policies for intervention that had earlier been developed for various travellers are applied according to the respective group's concerns. The purpose is to investigate the impact of combined policy interventions; it may be that applying combinations of policy interventions may cause effects that are unforeseeable and that might even be counter-productive (freely after Aristotle's saying "the whole is not merely an aggregate of its part").

The entire information in the policy formulation development table (Table 3) provided in Section 3.3 is adopted and specific interventions provided under each policy are presented in Table 7. In the table, the presence of '-' in any node is an indication that no intervention is provided for the concern in respect of the traveller's group involved.

Table 7: Combined policies intervention table

Concerns / Travellers	Comfort	Personal Mobility	Reliability	Safety/Security	Cost and Value for money	Convenience	Journey Time
Pedestrian	Make crossing facilities closer to each other; Reconfigure traffic light to give priority; Shelter along the routes	Regular pathways maintenance	Offline information access	Regular routes/pathways maintenance; Legislation against the bad road attitude	-	-	Information about possible diversions well before it occurs
Cyclist	Priority at junctions; Bigger shelter along routes; Traffic lights to give priority during bad weather	Legislate against lanes' obstructions	Offline information access	Campaigns on the need for safety of all road users; More protected cycle sheds with CCTV across the university; Good planning for cycle route signs	-	-	Good planning for cycle route signs; Obstruction-free route
Public transport user	Bus stops should be provided where there is currently none and bigger ones be added	-	Offline information access; Improvements in arrival time as advertised	Campaigns against unpleasant behaviour on public transport	-	Introduce busses in local routes where there are none	Increase bus frequency to the university operations; Introduction of additional buses.
Car user	-	-	-	-	Reduction in parking fee	More parking spaces	Real-time traffic information on all route within the city; Wider roads to ease traffic flow

Combined intervention on travellers' average daily satisfaction

The purpose of this experiment is to investigate the impact of combined interventions on the travellers' overall satisfaction. Figure 20 shows the average overall satisfaction of the four categories of travellers with the combined interventions applied at day 70. No intervention is applied to the car users.

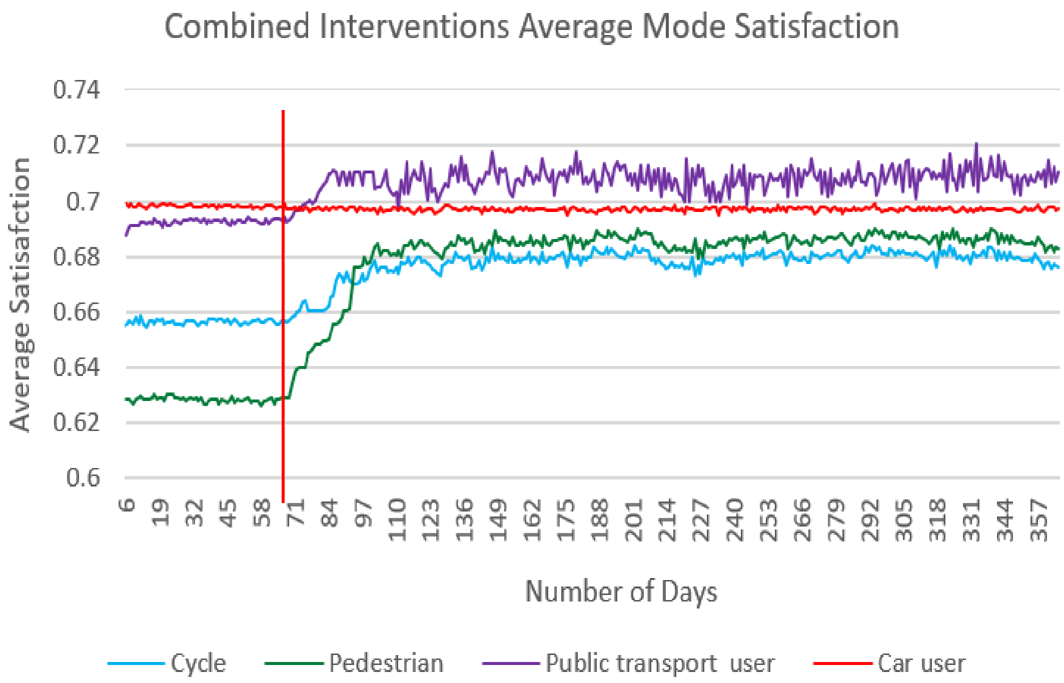


Figure 20: Combined interventions travellers' average daily satisfaction

The behaviour is observed until the end of 365 days. The figure indicates that pedestrians' average daily satisfaction settles at 69.0% after a gradual increase for over a period of 4 weeks. The improvement in pedestrians' average satisfaction is 11.3% higher than in the base scenario (62.0%). This shows that if a unit measure of combined interventions is provided, pedestrians are generally more satisfied. The proportion of dissatisfied pedestrians on one or more aspects of walking to the university is 47.8%. Among this group, 68.0% are concerned about the issues of protection from elements, 20.5% are dissatisfied with the level of pedestrians' safety due to the attitude of other roads users, the rest have concerns about walkways maintenance, reliable weather information and ease of getting to their destinations due to no direct routes. It is evident in Figure 20 that Human Factors and Psychology interventions have satisfied more than 80% of previously dissatisfied pedestrians.

For the cyclists' group, there is an increase in their average daily satisfaction from the base value of 65% to 68%, which is an increase of 4.6 %. The proportion of dissatisfied cyclists is 54.8% of the total cyclist's population. Among this group, 60% are concerned about safety as results of no dedicated cycle lanes, attitude of other road users to cyclists, and lack of route maintenance etc., 18% are concerned about protection from elements, and 15% are dissatisfied with delays due to lane obstructions and traffic light, the remaining population see cycle shed within the university as insufficient.

Furthermore, due to the large proportion of cyclists who are unhappy with the current safety provisions, the intervention mechanisms to improve the safety aspect of cycling to the university (e.g. campaigns against obstruction cycle routes as well as to respect cyclist right as equal road user) showed impact on the average satisfaction levels of the cyclists. For the public transport users, there is an increase of 2.1% in their average satisfaction, i.e. rising from 69% base scenario value to 71%. In this case, the interventions provided include increasing the frequency of the bus operations; increasing the reliability of the buses regarding advertised scheduled time, and shelters at the bus stop where there currently are none. The interventions can be observed to have shown improvements in public transport users' average satisfaction. The marginal increase recorded is due to the various small proportions of dissatisfied public transport users that have different concerns for various aspects of their mode. For instance, 12.7% of the dissatisfied users are worried about journey time due to the frequency of the bus, 7.3% are concerned about protection from elements at the bus stops, 3.64% complained about the attitude of other bus users, while 1.82% mentioned the aspect of getting on and off the bus etc. The interventions produced impacts not only on the proportion of dissatisfied travellers in population but also on the interactions that occur among them during the information-seeking process. The changes observed in Figure 20 affirms several ergonomics and transport psychology studies, including Stanton et al. (2013) and Roberts et al. (2017), about the interventions into travellers' mode choice from the perspectives of the two disciplines. Furthermore, it is worthwhile to state that the resulting impact of the improvements in individual travellers' overall satisfaction are also a result of the influence of the behaviour of other categories of travellers within the university transport system during interaction with satisfied individuals.

Combined intervention on travellers' mode shift pattern

Two sets of experiments are performed on the mode shift behaviour of travellers with combined interventions policies: (a) interventions excluding car users, and (b) interventions including car users.

(a) <u>Combined intervention excluding car users</u>

In this experiment, all seven categories of interventions are applied to the cyclists, public transport users and pedestrians. In Figure 21, the application of the intervention stimulates some of the travellers to shift mode to walking mode.

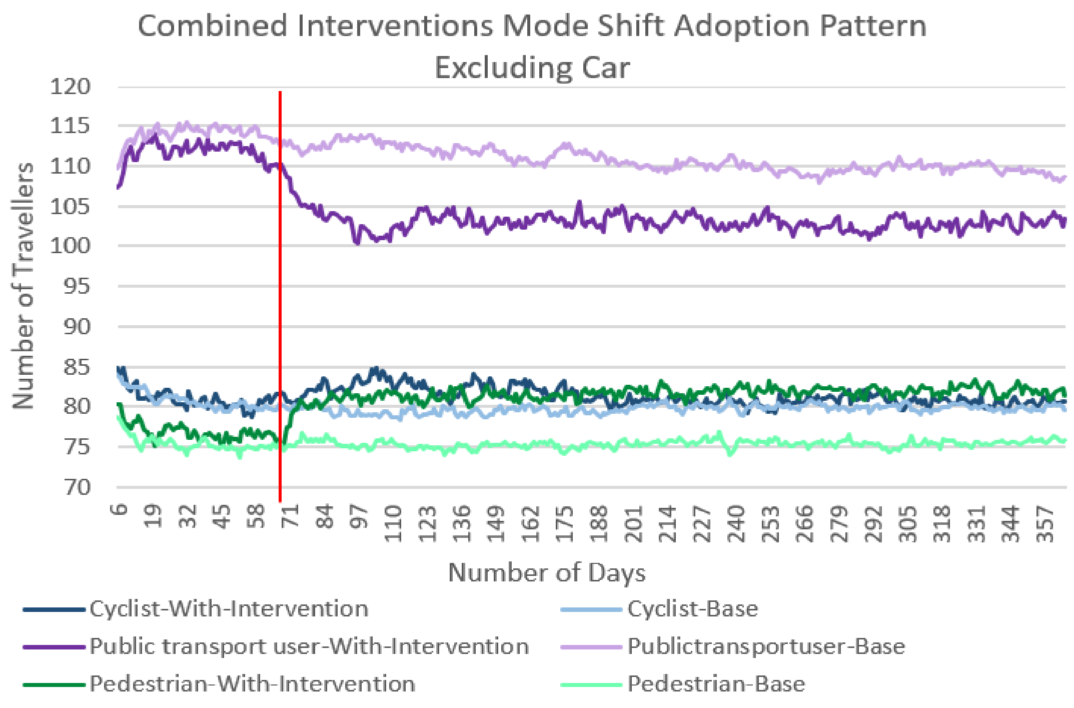


Figure 21: Combined interventions on travellers' mode shift adoption pattern excluding car user

This is evident in the gradual increase in the number of pedestrians to 75 after day 82 over a period of two weeks and the shift remains steady until the end of the simulation. The increase of 7.7% in the number of pedestrians' shows that a number of other travel mode users are attracted by the current improvement in the walking mode. About 7.7% of this group shift their travel modes to walking while other potential pedestrians are restricted by factors such as not residing within walking distance. For the cyclist's group, there is an initial increase of 6.3% in the cyclist number after the intervention. The increase reached a peak at day 102 before beginning to go down to initial setup value of 82 cyclists after 115 days of intervention.

The reason for the initial increase was a result of social interactions that occur between potential cyclists, who are aware of the new improvements and the regular cyclists in one hand, and due to potential cyclists and individual travellers, who personally engage in seeking information from the environment in order to update their knowledge on the other hand. The reduction in the number of cyclists after day 102 can be attributed to the behaviour of new adopters who owned a bicycle but preferred other travel modes to cycling. In addition, it could be that one or two of the constraints imposed on certain groups within the cyclists is not addressed and the level of interventions provided to respective concerns did not meet the satisfaction threshold of the new adopters. The situation provides a good hypothetic case to investigate the amount as well as the specific kind of interventions that need to be provided for observable impact to be achieved. For instance, a large proportion of cyclists are worried about various aspects of safety. The measure of intervention provided in this experiment is inadequate to sustain the behaviour of the group and the interaction among the potential cyclists and regular cyclists do not improve their perceptions. Regarding the shift in the public transport users' category, there was an increase in the numbers of public transport users from the setup value of 92 moves up to 112 before the interventions. This is due to the effects of social interactions among travellers (mostly pedestrians) who perceived public transport better than their mode or because of the average distance covered. However, the reduction of 8.7% in the number after interventions indicates that some of the public transport users are living within cycling and walking distance and hence form part of the adopters of the two travel modes.

(b) <u>Combined intervention including all travel modes:</u>

In this experiment, all seven categories of interventions are applied to the entire traveller population, including car users. Figure 22 presents the effect of the combined interventions. More measures that are peculiar to car users', such as more parking space and an increase in parking fee were included. The figure indicates that there is a 12% reduction in the number of car users to the university.

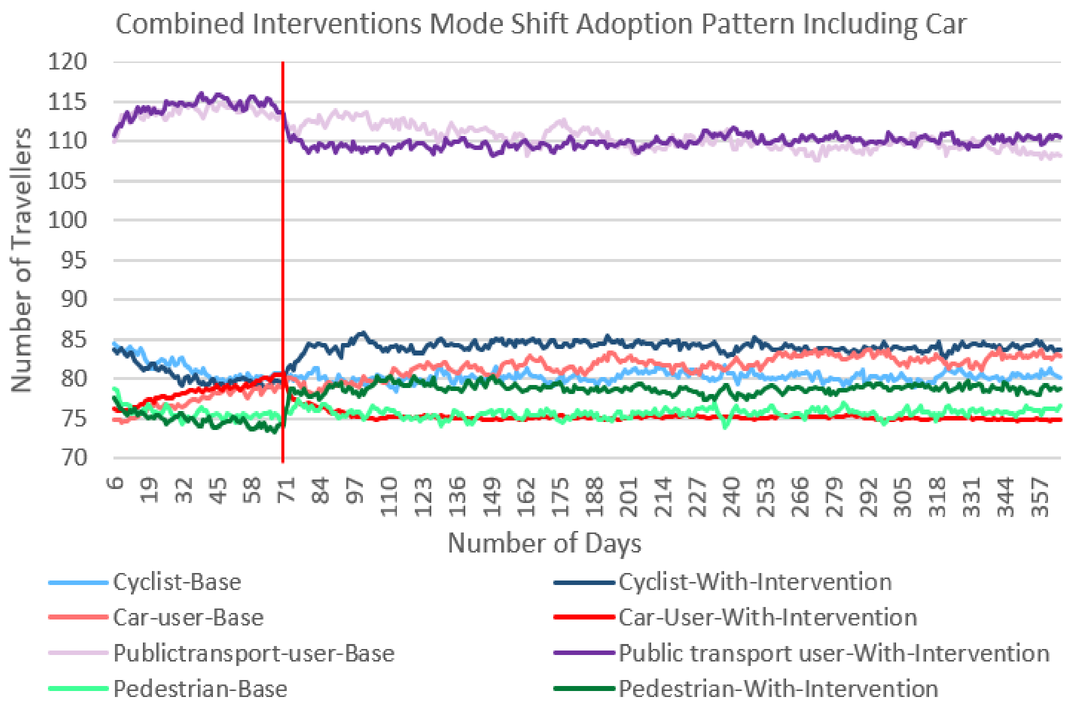


Figure 22: Combined intervention on traveller mode shift adoption pattern with car user

This implies that a certain proportion of car users has shifted their mode usage to other travel modes that satisfy their needs. The reason for the shift can be attributed to the increase in the parking fee. The survey data indicate that car users have concerns about the parking fees within the university.

For the cyclists, the proportion increases by 6.3%, the same proportion recorded at the early stage of the previous experiment without car users. However, in this scenario, the proportion of cyclist is sustained until the end of the simulation. One of the reasons for the behaviour of cyclists is the reduction in the number of car users on the road to the university, which encourage intending cyclists to cycle. Furthermore, the fact that the proportion recorded (i.e. 6.3%) as the peak of mode shift to cycle in both cases indicates that cycle ownership (i.e. access to bicycle) is an important factor for other travellers to adopt cycling. However, if the conditions that encourage new cyclists can be put in place and sustained, there is a likelihood of more travellers acquiring a bicycle for their journey to the university. The observable behaviour in the public transport group indicates that pedestrian and car users who do not own a bicycle or do not reside within a cycling distance but are dissatisfied with the new parking fee policy adopted the public transport. Furthermore, there is an increase of 5.3% in the pedestrian proportion after the intervention. This value is lower compared to 7.7% recorded in the interventions that excluded car users. The reason is that some pedestrians who are potential cyclists prefer walking to cycling because of the attitudes of some car users. However, travellers among the group that account for the difference, have adopted cycling in the scenario that excludes car users because of the reduction in the number of car users on their route to the university when the volume of car users reduced. From these experiments, it is evident that the application of a nudge to car users makes a significant difference in the behaviour of all other travellers to the university. It also indicates that some of the car users' daily distance travels are within the cycle and public transport travel range as indicated in the survey data. However, switching mode might not be practically possible for some car users, especially those who do not reside in the city but come to the university from other cities, or those who are emotionally tied to the car use.

The insights from the combined intervention that include car users are: (1) some car users can switch mode if other travel modes services are made better even without imposing further charges, and (2) some car users travel within walking, cycling and public transport range. Hence there might be other motives behind their habitual car usage which will require further investigations.

4 Discussion

Social simulation models such as the one presented in this study are theory-guided. The result of such simulations is mostly used for the development of explanations to make our environment better, rather than for accurate prediction of specific outcomes (Gilbert & Troitzsch, 2005). Our model demonstrated how a theory-based framework contributes to using survey data in numerical experiments that explore scenarios corresponding to real-life. The MOSH framework employed in our study contains components that allow the modelling of dynamics of travellers' activities in spatial and temporal dimensions. Its methodology includes the use of a generic data collection template that allows capturing travellers' views regarding the level of satisfaction and the importance attached to various aspect of their travel modes. The Human Factors discipline addresses the influence of the human environment on their performance. Therefore, it offers an important perspective on the constraints to modal shift, particularly regarding travellers' perceptions of the dissatisfied aspects of their travel mode. The CWA aspects of the MOSH framework provides an analytical modelling technique that supported the development of strategies to address the problems for the different categories of travellers. Furthermore, the Consumat approach as part of the framework provides adequate modelling capabilities to model the behaviour of various travellers with different needs, who also engage in a variety of decision making. The ABM approach taken in our study allows us the modelling of individual travellers so that the full effects of their diversity in characteristics and the emergence of their individual disaggregate behaviours can be observed.

Social simulations are generally useful to support the decision making process on policies. However, the validation process of social simulation models using statistical data has been identified to be complicated (Sun, 2006; Gilbert & Troitzsch, 2005; Jager & Janssen, 2012), due to the level of fieldwork required as well as parameterisation issues. Notwithstanding this fundamental limitation, our observation from the results of the experiments is that the level of data collected from our survey and the calibration of the model variables proved to be sufficient for the performance of our proof-of-concept model. The simulation results revealed hidden facts that could assist in policy formulations and implementations. For instance, the outcome of the comfort policy intervention shown in Figures 12, 13, 16, and 17 provided the basis for hypotheses on several policy implications. As presented in Section 3.5.3, applying a single policy measure to a set of travellers' concerns produced no observable impact on the mode usage behaviours of the travellers in most cases. The reasons for such behaviour indicate that some of the constraints do not individually impose serious difficulties on the travellers to the extent of discouraging their use of the mode. This could also point to the importance of considering the interdependency among various aspect of the transport system, which require appropriate interventions to be provided, before a significant impact can be observed. Hence, having such understanding about the scenario will assist stakeholders to channel efforts and resources for intervention to the areas of the system where they are more needed.

In addition, the improvements in the average satisfaction observed in the various policy interventions in the study affirmed the findings of some existing ergonomics and psychology studies such as Stanton et al., (2013). The study explained that constraints are interlinked and that the removal of one constraint could have effects on the remainder of the system. For instance, provision of ergonomics solutions such as shelters in possible areas along walkways for cyclist and pedestrian or interventions that reduced travel time for public transport will not only impact positively on the average travellers' satisfaction, it will also relieve travellers of some other difficulties inhibiting their decisions to adopt new travel mode that satisfies their needs. Moreover, other interventions that include campaigns against dangerous road habits and changes to traffic lights to give priority to pedestrians and cyclist during bad weather are related psychological interventions which had been identified to play a huge role in the behaviour of travellers by researchers such as Mann & Abraham (2006) or Steg (2003). Apart from the factors above, several individual characteristics also play roles in travellers' modal shift decisions. For instance, some of the travellers' daily travel distance to and from the university is outside of the pedestrian and cycle range distance, also, parental issues such as drop off kids in the school or day care will restrict mode choice behaviour of some travellers. The combined policy measure (see Figure 21) pointed out the importance of individual traveller characteristics such as travel days and daily distance range in travel mode choice to be considered. It also explains that a variety of policies can be targeted at different categories of travellers, based on their characteristics which is in line with findings from Osman et al. (2015). For instance, in this study, travel mode ownership has been identified to be an important factor in mode shift. It is therefore believed that if policy measures that encourage cyclists, for instance, can be put in place, more travellers from other categories who do not own a cycle could acquire one in order to adopt cycling as their travel mode.

In our experiments we have shown that the different policy measures can have profound impacts on the travellers' mode shift; the impact could be felt more, if the needs of different categories of traveller are targeted by an appropriate set of interventions. The study has also shown that in a social simulation model, different combinations of policies can be implemented, and the simulated outcomes of applying such policy combinations can be used to improve the implementation of a particular policy. This was demonstrated in the outcome of interventions that involved car users and those that do not involve car users which produced different behavioural pattern among the travellers.

5 Conclusion

This paper investigated the factors that influence travellers' mode choice decisions and examined the impact of policy interventions that can improve satisfaction and encourage mode shift among travellers. We used the MOSH framework to model the travel experience of a set of different types of travellers to/from a university. Our motivation came from the need to answer the following specific fundamental questions on issues regarding modal shift among travellers: (1) How can policymakers identify the factors within a transport system that determine travel mode choice? (2) How can policymakers gain insight into how the factors influence travellers' behaviour given the dynamics of activities and adaptive nature of the travellers within the system? (3) What impact do the social interactions among travellers have on their mode choice decisions?, and (4) Which policy measure or combination of policy measures would most effectively stimulate the behaviour of an individual traveller or a group of travellers towards adopting an alternative, environmentally friendlier, but less preferred travel mode?

Descriptive data on travellers' experiences on certain aspects of their travel mode was collected and analysed using AH and ConTA, which are Human Factors analytic tools incorporated as CWA into the MOSH framework. The analytic process not only revealed the constraints imposed on the individual or groups of travellers but also provided cues for appropriate policy development. The result of the ConTA provided various categories of travellers with their different needs, considering a number of different situations within their journey. This gave insight into the appropriate intervention to be provided. Seven themes of constraints were identified among the factors that determine travel mode choice behaviour of travellers. Strategies and policies to remove such constraints were formulated. The model was implemented and simulation experiments were executed, where different policy measures were applied as interventions.

Within this paper, we have presented some answers to the four questions mentioned above. Regarding our first question, how policymakers can identify the factors within a transport system that determine travel mode choice, the formative analytical processes involved in the study resulted in the identification of a number of travellers' concerns within the system. These concerns are factors that are paramount to travellers' mode choice and influence their decisions within the transport system. Regarding our second question, how policymakers can gain insight into how the factors influence travellers' behaviour given, the study presented various experimental outputs from both single and combined interventions. The visual outputs provided stakeholders with an understanding of how factors influence travellers' behaviour in a dynamic and adaptive sociotechnical system. For instance, cyclists and pedestrians have almost the same concerns regarding comfort in their journeys. The study shows that comfort intervention has a significant effect on pedestrians' mode shift pattern and social interaction behaviours but provided no significant improvement in the adoption pattern of cyclists. The insight from such behaviour indicates that cyclist population requires inclusive interventions that involve most of their suggested solutions to their concerns. Regarding our third question, what impact social interactions among travellers have on their mode choice decisions, the visual output from the travellers' cognitive processing behaviours provided insight into the levels of travellers' decisions that involve individual or social interactions as well as the decisions that involve automatic and reasoning processing to be made. The understanding of cognitive processing can assist policymakers to proffer solutions to some factors in the system that can further improve travellers' travel experience. Regarding our fourth question, which policy measure or combination of policy measures would most effectively stimulate positive behavioural change, is answered with a set of experiments. These include interventions with car users and without car users. For instance, cyclist adoption pattern in the experiment that excludes car users (i.e. non-interference in the car users' mode choice behaviour) shows an initial rise in the number of cycle adopters but later returned to the previous levels for this user group. This observed behaviour has been attributed to: (1) the level of intervention provided to various concerns that do not meet the satisfaction threshold of new adopters, and (2) that there is no improvement in the car users road usage behaviour, which is the main source of cyclists' safety concerns over time. These are the reasons for the return to their previous travel mode. In the interventions that involve car users, better adoption of other travel modes can be observed due to the number of car users who adopted the use of other travel modes. This can be attributed to the reduction in the numbers of car users going to the university as a result of the interventions.

More could be learned by selecting specific combinations of interventions using the links provided in the AH or the analytical output from CAT, as well as participants' concerns expressed in the survey data. What's more, a different combination of interventions to different circumstances can produce significantly different outcomes. In order to follow this up, an in-depth sensitivity analysis should be conducted. Another shortcoming of our current study design is that it is confined within the limited geographical area of a university. If the coverage is extended to the whole city, there might be possibilities of different outcomes in the mode choices of travellers.

Future work should overcome those limitations by running further case studies at city scale, and by running in-depth sensitivity analyses to unveil the full potential in terms of informative output these simulation models are able to produce. In addition, in order to add a new perspective, we propose to investigate the influence of travellers' PCA abilities on their travel mode choice decisions. Transport psychologists such as Wardman et al. (2001) and Steg (2005) suggest that travellers' abilities to satisfy travel requirements is an important factor in mode choice. The generic data collection aspect of the MOSH framework can be extended to include items that investigate the influence of these abilities on their mode choice decisions. When the resulting simulation model is executed, the impact of such abilities on mode choice can be identified. Also, insights into other areas including the constraints within the transport system that might not be earlier identified can be revealed hence, provide support for understanding improvements that are necessary.

This study has been designed to model a specific complex sociotechnical system where travellers in a transport system dynamically perceive their satisfaction level with respect to their context within the environment. The effects of their perceptions regarding their satisfaction level are visualised, and their mode shift behaviours are observed. The results of our investigations show that effective mode shift stimulation among travellers requires appropriate policy measures, specifically chosen for the different categories of travellers. A model, such as the one we developed for our study with the help of the MOSH framework can be a veritable tool for policymakers in forming and testing hypotheses on various behaviours that a set of travellers can engage in.

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Appendix 1

Passenger's Mode Shift Questionnaire

Introduction

In this questionnaire, you will be asked to answer a series of questions regarding your perception of your ***usual transport mode***. The questions focus on your perception, attitude and ability to make use of the transport mode, and they assess the importance and satisfaction on ***"Planning for your main journey"***. The purpose is to examine how this concept can impact decisions of the traveller to choose a mode of transport to the University of Nottingham.

Task Instruction

The questionnaire consists of two sections:

- Section A: the general information.
- Section B: the perception on travel mode usage experience.

SECTION A: GENERAL INFORMATION

In this section, you are to *tick or write (where applicable) as appropriate.*

Q1: What is your gender?

☐ Male ☐ Female ☐ Prefer not to say

Q2: Your age:----------

Q3: What is your ***usual transport mode***? Choose most often used transport mode to the University.

☐ Personal Vehicle ☐ Public Transport ☐ Cycling ☐ Walking

Q4: What is the usual purpose of your trip? **(Tick all that apply)**

☐ Weekdays commuting to/from work
☐ Business travel
☐ Weekdays commuting to/from education

Q5: Which of the following best describes your occupation?

☐ Professor/Senior Academics
☐ Other Academics
☐ Professional/Senior Managerial
☐ Middle Managerial/Administrative
☐ Junior Managerial/Clerical
☐ Skilled Manual
☐ Unskilled Manual
☐ Full-time Student
☐ Part-time student
☐ Retired

Q6: If you have used more than one mode of transport for your typical trip, which <u>other transport modes</u> do you usually use as ***part of a single journey***?

Note: if primary transport mode is a tram, but you walk to the tram stop, please tick "walking" in this question as your additional mode of transport (Question 3 takes care of your primary mode).

☐ Car
☐ Bus or Coach
☐ Rail
☐ Tram
☐ Motorcycle
☐ Taxi
☐ Bicycle
☐ Walking
☐ N/A

Q7: How far do you have to travel in miles before you get to your primary transport mode? ***(If Applicable)***

a. Going Out:---------------------
b. Returning:---------------------

☐ N/A

Q8: What is your usual travel time on your transport mode (e.g. Going Out: 9:30, Returning: 17:30)?

a. Going Out:------------------

☐ No specific time

b. Returning:-------------------

☐ No Specific time

Q9: What is your average daily distance round trip commute in miles on your transport mode? ----------

Q10: How long have you been using your transport mode for the purpose indicated in Q4?

☐ 1 month
☐ Under 1 year
☐ 1-2 years
☐ 3-4 years
☐ 5-6 years
☐ 6 or more years

Q11: How often do you use your transport mode?

☐ Every day
☐ 3 or more times a week
☐ Once or twice a week
☐ 1 or 2 times a month
☐ Once every 2-3 months
☐ Once every 4-6 months
☐ Less often
☐ Never/ first time today

Q12: If you have any disability, does your condition or illness have an adverse effect on your ability to make use of your travel mode?

☐ All the time
☐ Often
☐ Sometimes
☐ Rarely
☐ Never
☐ N/A

SECTION B: PERCEPTION ON MODE USAGE EXPERIENCE.

Planning for your main journey:

The following questions focus on your perception of planning for your main journey using your typical transport mode.

13. How important are the following in planning for journeys on your usual travel mode?

	Very Unimportant	*Somewhat Unimportant*	*Neither Important Nor Unimportant*	*Somewhat Important*	*Very Important*	*Not Applicable*
a. Information provision (e.g. timetabling)	○	○	○	○	○	○
b. Timeliness of the travel mode	○	○	○	○	○	○
c. Reliability of the travel mode	○	○	○	○	○	○
d. Frequency of the travel mode	○	○	○	○	○	○
e. Speed of the travel mode	○	○	○	○	○	○
f. Physical ability required	○	○	○	○	○	○
g. Security	○	○	○	○	○	○
h. Safety	○	○	○	○	○	○
i. Autonomy/Privacy	○	○	○	○	○	○
j. Control over your journey	○	○	○	○	○	○
k. Protection from poor weather	○	○	○	○	○	○

14. How satisfied are you with the following on a typical journey on your commute to the University?

	Very Unsatisfied	*Somewhat Unsatisfied*	*Neither Satisfied Nor Unsatisfied*	*Somewhat Satisfied*	*Very Satisfied*	*Not Applicable*
a. Overall satisfaction on planning for the journey	○	○	○	○	○	○
b. Reliability of the available information about the main mode	○	○	○	○	○	○
c. Ease of accessing information about the main mode	○	○	○	○	○	○
d. Ease of getting to your main travel mode (e.g. route leading to mode stop)	○	○	○	○	○	○
e. Ease of getting to your destination on time	○	○	○	○	○	○

f. Ease of getting on and off your travel mode (if applicable)	○	○	○	○	○	○
g. Distance to main travel mode (if applicable)	○	○	○	○	○	○
h. frequency of the main mode (if applicable)	○	○	○	○	○	○
i. Parking space concern	○	○	○	○	○	○
j. Delays	○	○	○	○	○	○
k. Security enroute the main mode	○	○	○	○	○	○
l. Safety on the main mode	○	○	○	○	○	○
m. Availability of signs (e.g. road, wayfinding, pedestrian etc.)	○	○	○	○	○	○
n. Attitude of other passengers	○	○	○	○	○	○
o. Walking from your main travel mode to your destination	○	○	○	○	○	○
p. Protection from poor weather	○	○	○	○	○	○

15. If you have chosen “Very Unsatisfied” or “Somewhat Unsatisfied” in any of the items in question 14. List the item letter and your reason(s) for being unsatisfied

16. What changes could be made to improve your level of satisfaction?