ROAD TO HEALTH: STIMULATING CHANGES IN TRAVELLERS' MODE CHOICE FROM MOTORISED TRAVEL TO NON-MOTORISED TRAVEL USING AGENT-BASED MODELLING APPROACH

OLUSOLA THEOPHILUS FABOYA*

Department of Computing and Information Science, Bamidele Olumilua University of Education, Science and Technology. Ikere-Ekiti, Nigeria.

ABSTRACT

This study investigated how both ergonomics and psychological factors within the non-motorised transport environment impact the travellers' decisions to travel with the modes on their short-distance journeys so as to assist policymakers in making informed decisions.The study examined the public views in the City of Nottingham, United Kingdom regarding the challenges associated with short-distance journeys (e.g., getting to the grocery store) with non-motorised travel modes, with a view to improving their travel experiences. An agent-based social simulation framework for modelling agents' adaptive nature with spatial and temporal perception in a dynamic system was used to answer the identified specific questions.The procedure for data collection involves an initial interview and a questionnaire. From the interview, travellers' Comfort, safety, convenience and journey timewere identified as the main source of concern to both regular non-motorised travellers and motorised travellers. A questionnaire was administered to 740 respondents that included 220 non-motorisedtravellers that consisted of 70 females and 150 males and 520 motorisedtravellers included 310 females and 210 males in the study. The analysed data form the base parameter for the simulation model.In the model experimentation, two policy interventions were compared to the base scenario and responses that include the travellers' mode shift diffusion pattern and travellers' cognitive processing pattern were observed and analysed. It was concluded that the study satisfied the aim of providing support for policymakers to answer specific questions that include 1) identifying areas of transport infrastructure to be improved, 2) identifying the combination of policies and interventions that could stimulate travellers'behaviour and 3) gaining insight into travellers' psychological concerns. The study revealed that difficulties in providing 'luggage carrier' interventions on non-motorised travel modes reduce the potential for increasing these travel modes for everyday journeys and that the impact of social interactions contributed to a shift in non-motorised modes' adoption. It further revealed that there is interdependency among system components due to the interplay between ergonomic and psychological factors. These findings need further investigation with scenarios that include different interventions in future.

.

Keywords: [motorised travel, non-motorised travel, agent-based modelling MOSH framework)

1. INTRODUCTION

The challenges of constant reliance on cars and other motorised travel modes are beyond traffic congestion and environmental pollution; it includes health-related problems brought about by insufficient physical activity (Giles-Corti et al., 2010;Davison & Curl, 2014). Engaging in non-motorised travel allows people to meet the recommended level of exercise just by making everyday journeys while addressing the challenges of motorised travel dependency. Encouraging non-motorised travelin society will contribute to the reduction in greenhouse gas emissions and ensure a healthier lifestyle which could save individuals and the government from spending on health conditions linked to physical inactivity.

There has been an increased focus on the need for sustainable travel for a healthy lifestyle in recent times. There are also increased works that promote non-motorised transport engagement across disciplines including Built environments, Transport geography and Transport Psychology (Manaugh & El-Geneidy, 2013; Gehlert et al., 2013). Despite the awareness, car dependence is still a major issue in many societies. Even today, many short urban trips including visiting nearby groceries are made in private vehicles. French et al. (2014), observed that nine out of ten short-distance trips could be completed by public transport and non-motorised modes of transport such as walking, cycling, skateboarding, and scootering but travellers preferred motorised travel. Pooley et al. (2011) had earlier attributed the behaviour to a combination of reasons that include ergonomics and psychological aspects. The ergonomic factors come as a result of the constraints imposed by the transport environment on the activity of the travellers, which in turn give rise to psychological aspects. Apart from this, the relationship between the interrelated components of the transport systems makes understanding travellers' preferences difficult (Faboya et al., 2020). It becomes more challenging when the psychology of the active agents in the dynamic system is involved (Gehlert et al., 2013). Although, Roberts et al. (2017) suggested a change in the travellers' mode choice behaviour as a short-term solution to the problems with reduced costs. Such a goal could be achieved by effective policy formulation that involves both transport infrastructural improvement and complementary appropriate interventions that involve taking care of the travellers' psychological concerns.

Consequently, a detailed understanding of both factors on travellers' mode choices is necessary so as to stimulate their behaviours. Therefore, within the identified problems, the following questions need to be answered: (1) how can policymakers identify the areas of transport infrastructure to be improved? (2) how can policymakers gain insights into the combination of policies that would effectively stimulate the behaviour of individuals or groups of travellers towards adopting non-motorised travel mode? (3) how can policymakers gain insights into the travellers' psychological concerns?

This study aims to investigate how both ergonomics and psychological factors within the non-motorised travel environment impact the travellers' decisions to travel with the modes that require more physical abilities on their short-distance journeys. In this paper, an agent-based social simulation study for a set of travellers is presented to answer the identified specific questions. The study examined the public views in the City of Nottingham, United Kingdom regarding the challenges associated with short-distance journeys (e.g., getting to the grocery store) with non-motorised travel modes, with a view to improving their travel experiences. In the study's modelling stage, a structured approach presented by the MOdalSHift (MOSH) framework by Faboya et al. (2017) is followed. The MOSH framework is an agent-based modelling framework for modelling adaptive nature with the spatial andtemporal perceptions of agents in a dynamic sociotechnical system. The outcome of the investigation assists policymakers to gain insight into factors including ergonomics, psychological and other factors that need to be considered to stimulate motorisedtravellers'behaviour towards the adoption of non-motorised travel.

The remainder of the paper is organised as follows: Section 2 discusses the background to the study which includes the overview of the MOSH framework and related works. Section 3 describes the model development and details of model implementation. Section 4 presents the discussions and findings. Finally, Section 5 presents the conclusions and proposes further ideas for future work.

2. BACKGROUND

Transport system as a sociotechnical system involves the technical aspects, operational processes and people who use and interact with the technical system (Sommerville, 2016). Organising the way people travel sustainably in such a complex system is a key challenge. The relationship between the interrelated components of a transport system makes understanding travellers' preferences a difficult issue. It becomes a greater challenge when the psychology of the active agents in the dynamic system is involved (Gehlert et al., 2013). Transport Psychologists including Mann & Abraham (2006); Pooley *et al.* (2011); Pooley *et al.* (2013) and Gardner & Abraham (2007) had earlier used static interpretative phenomenological analysis and grounded theory analysis respectively to investigate psychological factors on travellers' decision-making. Their works did not consider the influence of social interactions among travellers. Besides, other notable transport psychologists have pointed out the neglect of important factors that determine mode choice behaviour in active travel. For instance, Lindelow (2013) argued that walking is a function of an individual's interaction with and perception of the environment, rather than simply being environmentally determined. In another study, Lindelow et al. (2014) brought to light the need to understand that individual time/space influences the feasibility of walking for everyday activities which also applies to other non-motorised travel modes. Davidson (2013), Talen and Koschinsky (2013) and Rind et al.

(2013) questioned the normative idea that a walkable environment is good for everyone without considering individual attributes and capabilities among the social groups. Gantner & Kerschbamer (2018) and Flache et al. (2017), in separate studies also showed that social interaction drives a decision-maker to make his choice dependent on what he observes others in his reference group do. Furthermore, Faboya et al. (2018) argued that there are individual differences in terms of ability, cognitive and affective aspects which determine travellers' preferences in transport choice.

To achieve the aim of finding answers to the specific questions stated, the idea of the complex adaptive system (CAS) (Holland, 2006) and Agent-based modelling (ABM) Bonabeau (2002) that supports the process of understanding the operations and interactions in a sociotechnical system's components would be appropriate. Therefore, in the following sub-section, we discuss CAS, ABM and the modal shift framework used in this study.

2.1 Complex Adaptive System and Agent-based Modelling

A CAS is a system with a large number of agents which interact, learn, and adapt to changes in their environment in order to improve their future survival chances (Oughton *et al*., 2018). An agent is an autonomous decision-making unit with diverse characteristics that have behaviours, learn from experiences, interact, and influence each other. Agents are capable of changing their behaviours during the simulation in an adaptive system as they learn and encounter novel situations, or as populations adjust their composition to include a larger proportion of other agents who have successfully adapted. Among the modellingtechniques for CAS, Bonabeau (2002) suggested Agent-Based Modelling (ABM) as a suitable computational method. ABM provides a better way of representing an individual 'agent' with varying attributes, modelling context-dependent action and implementing qualitative behaviour rules (Macal & North, 2009). The agent-based paradigm had been applied in many studies that involve traveller's behaviour in transport systems. In the following section, we provide an overview of the agent-based MOSH framework we used in this paper.

2.2 Modal Shift Framework

The MOSH framework shown in Fig 1 is a standard conceptual tool to model modal shifts in the transport system and provides experts from different disciplines the opportunity to model with different perspectives. MOSH considers the heterogeneity in travellers' traits and accounts for their contexts in the process of trip-making within an uncertain and dynamic transport system. MOSH framework works on the principle that the challenges that prevent travellers to adopt non-motorised travel on short distances can be perceived from travellers' mode usage behaviours within the system environment. Such situations call for fact-finding and knowledge-gathering about what the problems could be. The outcome of the analytic process using the framework and the survey data gathered would be the basis for the strategic development of interventions to simulate travellers'behaviours.

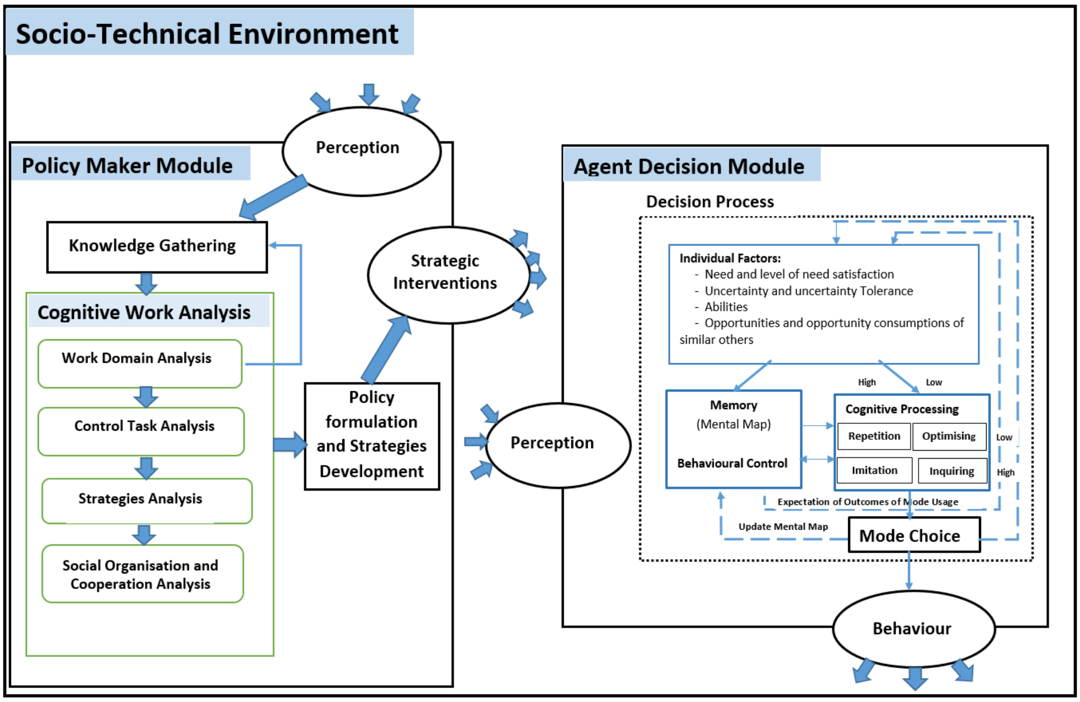

Fig 1: Modal Shift (MOSH) Framework (Faboya et al., 2017)

The MOSH framework consists of three basic modelling components: (1) the Socio-technical environment within which the policymaker and the individual travellers that make decisions operate. The environment is the decision context of the travellers(Jager & Janssen, 2012) that contains the available resources that are applicable to all travellers irrespective of their status. (2) policymakers module, represents the stakeholders that are equipped with the Cognitive Work Analysis (CWA) (Vicente, 1999; Rasmussen *et al.* 1994) to achieve the understanding of the transport system's constraints (temporal/spatial) on travellers' decisions. Policymaker has the role of fact-finding, analysis and strategic developments whenever there is perceived (un)pleasant situations in the transport environment. (3) the Agent Decision Module is based on Jager (2000) and Jager & Janssen (2012)Consumat approach which organises different social, psychological and economic theories in a unified conceptual framework for agent-based modelling for modelling an aspect of human decision (Faboya, 2020).The MOSH framework integrated two major components into its modelling process to achieve the objectives of analysing the dynamic activities and adaptive nature of travellers within complex transport systems. The first component is the CWA, which has four out of its original five analytical phases included in the framework. Each phase of CWA models a different set of constraints within a system. The overview of CWA phases is detailed in (Naikar et al., 2006; Naikar, 2006). In this paper, the use of the CWA aspect of the MOSH framework covers the Work Domain Analysis (WDA) and the Control Task Analysis (ConTA).

The WDA uses the Abstraction Hierarchy (AH) to models:1) the fundamental set of constraints within the transport system, 2) the process of using the transport system's components (transport infrastructure) and 3) how the system components impact travellers' mode choice process. ConTA is the second phase of the CWA that models the context of the traveller by focussing on which activity can be achieved independently of how it is conducted or who undertakes it. ConTA has been used in many studies including military (Neelam Naikar, Treadwell, & Brady, 2014), rail transport (Stanton et al., 2013) and in the variability of users' behaviour(Cornelissen et al., 2013).

The second major component of the MOSH framework is the Consumat component. A well-researched conceptual model that integrates several known social-psychological theories for studying an aspect of human decision process. It provides MOSH framework with modelling travellers' decision process using the key behaviour's driving factors that include their previous experiences with the travel modes usage and their current mental state, which are updated on the basis of the cognitive processes and their information-seeking strategies guided by the decision module components of the MOSH framework (Faboya et al., 2017).

3. CASE STUDY

The case study described in this paper examines the public views regarding the challenges associated with short-distance journeys (e.g., getting to the grocery store) with travel modes that demand physical efforts in a city. The purpose of the study is to investigate how the identified travellers' concerns impact the travellers' decisions and with a view to improving their travel experiences. The perception is that both ergonomics and psychological factors within the non-motorised travel environment impact the travellers' decisions to travel with the modes on their short-distance journeys. In our case study, a traveller on a short-distance journey can choose from walking, cycling, skateboarding and scootering.

3.1 Data Collections

The procedures for data collection and analysis are detailed in (Faboya, 2020)[1]. In this paper, an overview of the data collection and analysis process relevant to the study is resented. The data collection procedure involves an initial interview where travel mode concepts are identified. From the interview, four themes: *comfort, safety, convenience and journey time*were identified as the main source of concern to both regular non-motorised travellers and motorised travellers. These are used as measures of performance for each travel mode later in the study. Furthermore, a questionnaire that focused on travel modes' attributes that are of concern to the travellers was used in the data collection process. The selected transport environment features are:*sidewalks and cycle paths and footpaths, crossing facilities and road signs, the attitude of other road users, route availability and obstruction-free routes, facilities (e.g., shower) at the destination, journey time consideration, capability for carrying luggage, shelter from elements and health benefit of active living.* The validation and reviews of the questions were made by consulting experts in Human Factors and the Transport operations domains. The feedback resulted in several iterations of the questionnaire. In the end, we jointly concluded that the questionnaire was fit for the purpose.

There are three sections in the questionnaire, the first focussing on demographics which collected participants' responses on basic information such as age, gender, usual travel mode for a short distance, etc. The second focuses on non-motorised transport users' perceptions, this consists of a Likert scale and open-ended questions. The Likert scale question measures how satisfied a traveller is with the attributes of the non-motorised travel mode under consideration. The last focus on the motorisedtravellers' experience which consisted of Likert scale that measures the likelihood of a motorised user to adopt non-motorised travel in the future and a subsection that collected responses for reasons for not being a non-motorised travel mode user and subsequent suggested solutions to improve the situation. The questionnaire was administered through physical distribution. The 740 respondents in the study include220 non-motorised travel mode users, 70 females and 150 males, aged between 19 and 53 years (including ten (10) respondents that indicated the use of two non-motorised travel modes.520 motorised travel mode users, 310 females and 210 males aged between 21 and 62 years.

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

3.2 Data Analysis

Table 1 shows the relationship that exists among various aspects of the non-motorised transport environment considered in the study and the criteria for evaluating the performance of the travel modes regarding the travellers' needs. The needs of non-motorised travellers on their short distance

[1]Initial interviews were conducted amongst regular non-motorised and motorisedtravellers to gain insight into the current situation of the relevant infrastructure and resources within the non-motorised transport environment in the city of Nottingham. Questionnaire was used in the data collection process. The 740 respondents to the questionnairecomprised 220 non-motorised travel mode respondents including ten respondent that indicated the use of two non-motorised travel modes and 520motorised travel mode respondents. An agglomerative hierarchical clustering algorithm was used to identify the three distinct stereotypes present in the non-motorised population. The information from the quantitative analysis was used in the simulation parameterisation. Further analysis of the textual data revealed facts that assisted in the policy formulation and strategies for intervention.

journey are the provision of *safety, convenience* and *comfortable* journey to and from their destinations.

Table 1. Non-motorised transport functional purpose relationship table

The aspects of the non-motorised mode investigated	The related transport system concept	Criteria for performance evaluation
(A) Sidewalk ways/Cycle lanes /Footpaths etc.	**Route provision** (A) and (B)	**Safety** <u>Contributing factors:</u> -route provision. -protection and measure of safety. -traffic controls
(B) Route availability and obstruction-free routes.	**Protection and measures for safety** (A), (B), (C), and (D)	
(C) Crossings and road signs at Junctions.		
(D) The attitude of other road users.	**Traffic control regulations** (C) and (D)	**Conveniences** <u>Contributing factors:</u> -route provision. -traffic controls. -luggage carrier.
(E) Capabilities for luggage carriage.	**Luggage Carrier provision** (E)	
(F) Shower and other facilities at the destination.	**Comfort facilities provision** (F)	**Comfort** <u>Contributing factor:</u>
(G) Journey time consideration.	**Travel time consideration** (G)	**Journey time consideration** <u>Contributing factors:</u> -travel time considerations. -route provision. -traffic control regulations.

To better illustrate the relationships that exist among the elements of

The aspects of the non-motorised mode investigated	The related transport system concept	Criteria for performance evaluation
(A) Sidewalk ways/Cycle lanes /Footpaths etc.	**Route provision** (A) and (B)	**Safety** <u>Contributing factors:</u> -route provision. -protection and measure of safety. -traffic controls
(B) Route availability and obstruction-free routes.	**Protection and measures for safety** (A), (B), (C), and (D)	
(C) Crossings and road signs at Junctions.		
(D) The attitude of other road users.	**Traffic control regulations** (C) and (D)	**Conveniences** <u>Contributing factors:</u> -route provision. -traffic controls. -luggage carrier.
(E) Capabilities for luggage carriage.	**Luggage Carrier provision** (E)	
(F) Shower and other facilities at the destination.	**Comfort facilities provision** (F)	**Comfort** <u>Contributing factor:</u>
(G) Journey time consideration.	**Travel time consideration** (G)	**Journey time consideration** <u>Contributing factors:</u> -travel time considerations. -route provision. -traffic control regulations.

, the seven items in column 1 that contain the aspect of the travel mode on which survey data are sought are labelled alphabets A to F. Relevant items of column 1 are listed under the corresponding transport concepts that they are related to in column 2; and column 3 contains the criteria for measuring the system's performance. For instance, it can be seen that *sidewalks, cycle lanes, footpaths,route availability and obstruction-free routes* are related to the *route provision* in column 2. Also, one or more travel mode concepts in column 2 such as route *provision, protection and measure for safety*, and *traffic control regulations* contribute to the travel mode support for *safety* as indicated in column 3.

3.2.1 The Construction of the Study's Abstraction Hierarchy

The resources considered in this study as provided in

The aspects of the non-motorised mode investigated	**The related transport system concept**	**Criteria for performance evaluation**
(A) Sidewalk ways/Cycle lanes /Footpaths etc.	**Route provision** (A) and (B)	**Safety** Contributing factors: -route provision. -protection and measure of safety. -traffic controls
(B) Route availability and obstruction-free routes.	**Protection and measures for safety** (A), (B), (C), and (D)	
(C) Crossings and road signs at Junctions.		
(D) The attitude of other road users.	**Traffic control regulations** (C) and (D)	**Conveniences** Contributing factors: -route provision. -traffic controls. -luggage carrier.
(E) Capabilities for luggage carriage.	**Luggage Carrier provision** (E)	
(F) Shower and other facilities at the destination.	**Comfort facilities provision** (F)	**Comfort** Contributing factor:
(G) Journey time consideration.	**Travel time consideration** (G)	**Journey time consideration** Contributing factors: -travel time considerations. -route provision. -traffic control regulations.

are used in the building of the AH shown in Fig 2. Our focus is on the impact of the non-motorised travel mode attributes on the four concerns of travellers indicated as the value and priority measures of the AH.A traveller's safety has a direct link with safe and secured sidewalk ways, footpaths, cycle lanes, attitude of other road users, etc. Travellers' conveniences are related to the capacity to carry luggage on their short-distance journeys, accessible crossing facilities that are not too far apart, etc. The comfort of non-motorised travel modes includes the provision of facilities that support the biological needs of a traveller (e.g., bathroom). Finally, journey-time consideration includes up-to-date information about diversions, efficient route provision and traffic controls.

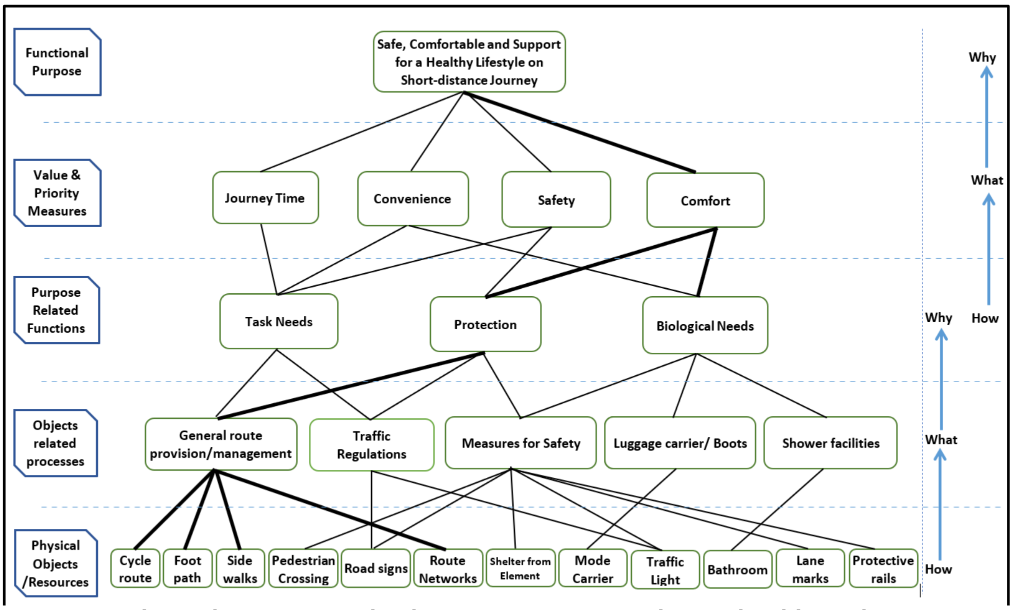

Fig 2: The Non-motorised transport system's abstraction hierarchy

The AH is constructed using its natural *"how-what-why"* triads. To illustrate how we created these triads, focussing on the highlighted nodes and means-ends links in the AH: if for instance, *comfort* is taken as the 'what' at the *values and priority measures* level, the means-end links connecting to the nodes up to the higher level of abstraction show that it can support a safe, comfortable and healthy lifestyle on a short-distance journey at the functional purpose level. To show how the comfort node ('what') has been derived, it can be seen that thetraveller's protection and biological needs 'How') supported its formation. The same process is used to form the rest of the links in the AH.

3.2.2 Construction of contextual activity template

The technique to investigate the impact of context (temporal/spatial) on the travellers' decision is one of the strength of MOSH framework. The *Control Task Analysis (ConTA)* introduced by Naikar*et al*. (2006) and included in the MOSH framework uses the contextual activity templates (CAT) shown in Figure 3 to model known recurring travellers' activities within the system.

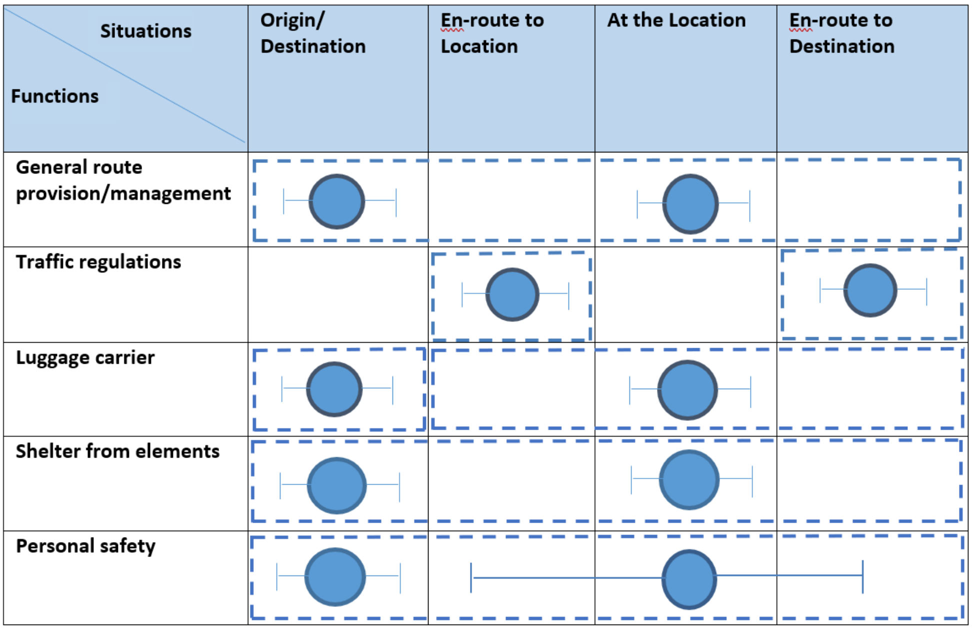

Fig 3: Contextual Activity Template for the non-motorised travel environment

3.2.3 Policy Formulation and Strategic Intervention Development

The AH in Fig 2 and the CAT analysis in Fig 3 assisted in identifying the needs of individual travellers or a group of travellers within the context of the travel mode facilities that support the achievements of the needs. Based on the concerns of different categories of travellers, strategies are developed, and policies are formulated for interventions. The strategies are developed around the five metrics in the values and priority measures level of the AH which are used for performance evaluation (as listed in Table 1).

The suggested solution to address *sidewalk ways/cycle lanes and footpaths* concerns include the creation of dedicated lanes for cyclists along the roads; good planning and maintenance policies for walkways, footpaths and cycle lanes. It can be observed that the suggested solutions centre around *Conveniences* in the ease of performing tasks and improvements in the time taken (*Journey time*) to travel to destinations. For the *route availability and obstruction-free routes* concerns, the following solutions are suggested: campaigns and public enlightenment on the need for obstruction-free routes; legislation against route obstructions and long notification and alternative routes for construction works; and building of routes with limited interference with motorised travel modes. the solutions address travellers' concerns on s*afety* and *journey time consideration*s. The intervention for the travellers' concerns on *crossing and road signs at junctions* includes installation of more crossing facilities at intervals to reduce the distance between successive crossing installations and reconfiguration of the traffic control system to give priority to non-motorisedtravellers during bad weather such as rain, snow etc. Such interventions may promote the likelihood of motorisedtravellers changing to non-motorised travel modes. The solution centre around resolving concerns regarding travellers'*safety, convenience* and *journey time* consideration. The suggested strategies to address non-motorisedtravellers' concerns about the *attitude of other road users* include the provision of dedicated lanes for non-motorisedtravellers, campaigns on the rights and safety of all road users as well as legislation against bad driving. More CCTV cameras be installed on the streets that primarily rely on neighbourhood watch. Travellers'*safety* is the main criterion to measure. Non-motorised concerns regarding luggage carrier is classified as 'hard constraints' (Stanton *et al.,* 2013). Interventions to such challenges are mostly through manufacturer design initiatives (e.g., the inclusion of luggage carriers in the travel mode design) rather than a policymaker initiative. In general, there are no specific suggestions from the travellers' survey response on how the concerns of the luggage carriers could be resolved. However, attachments (e.g., baby-carrier) can be provided for use with cycles to address the problem. The luggage-carrying capability of a travel mode is measured by the level of *convenience* a traveller enjoys. Non-motorisedtravellers to short-distance workplaces and education are more about showers and other facilities to refresh at the destination after long walking or cycling discouraged many motorisedtravellers from adopting non-motorised travel. A policy on non-motorised travel support facilities in all public organisations is required. This should be made mandatory just like the wheelchair ramps legislation. Such a policy could encourage workplace-bound motorisedtravellers to adopt non-motorised travel so as to address t*ravellers' comfort*. Generally, many non-motorisedtravellers showed concerns about the longer time taken to travel compared to motorised travel. Hence, the reasons for their need to set out earlier for their journeys. Other major contributors to journey-time concerns are *route availability and obstructions*, and*crossing facilities.* While *Journey-time* as a concern on its own can be difficult to address in the context of non-motorised travel, the interventions provided for journey-time related challenges will assist in removing some of the challenges.

3.2.4 Identifying the Stereotype within the non-motorisedtravellers' population

An agglomerative hierarchical clustering algorithm for unsupervised learning was used on the datasets to identify the stereotypes within the population of non-motorisedtravellers that have similar perceptions of the travel mode properties.

The result of the classification is presented in the dendrogram Fig 4

ISSN: 2278-6252
Impact Factor: 7.687

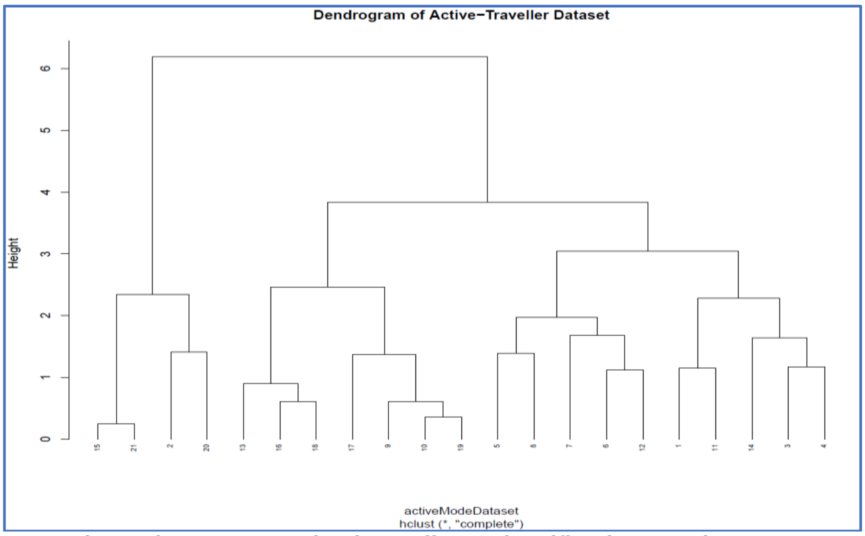

Fig 4: The Non-motorisedTravellers' Classification Dendrogram

The dendrogram is viewed at height 3, and three different groups emerge from the population. The boxplots that represent the members of the three groups are presented below:

The boxplots in Fig. 5 shows the distributions of the set of travellers stereotyped as group 1 (i.e., the right arm of the dendrogram from height 3)

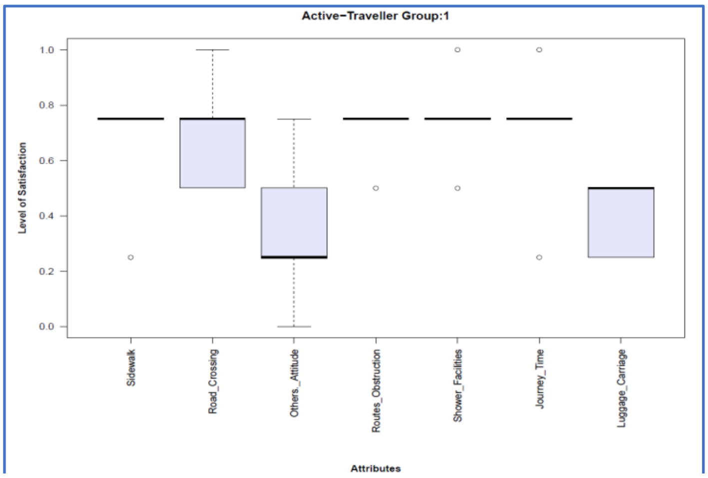

Fig 5: Boxplot for Non-motorisedTravellers' Group 1

The members of group 1 are satisfied in all the aspects of the non-motorised travel mode attributes except in the *other travellers' attitude* and *luggage carrier* attributes where the group is most dissatisfied. Few outliers around the upper, middle and lower bound of the *sidewalk* and *journey-time* attributes are indications of dissatisfaction with these attributes.

Fig. 6 is the boxplot representation of the travellersstereotyped as group 2 (the middle arm of the dendrogram from height 3). The distributions in the boxplots indicate that this group is satisfied in all aspects of their non-motorised travel mode.

ISSN: 2278-6252
Impact Factor: 7.687

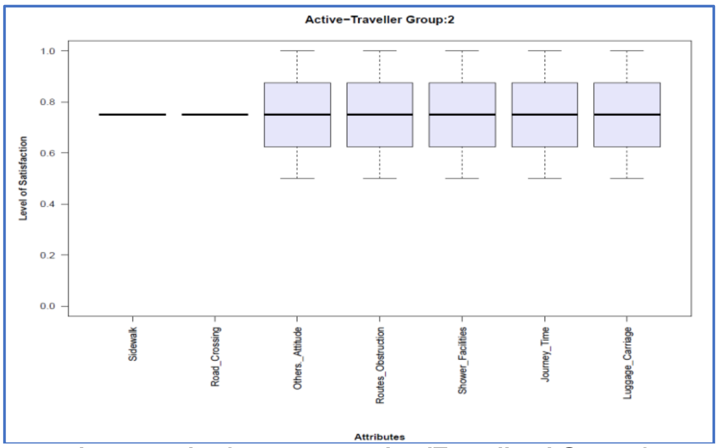

Fig 6:Boxplot for Non-motorisedTravellers' Group 2

The boxplot distributions in Fig 7represent non-motorisedtraveller group 3 (the left arm of the dendrogram from height 3).

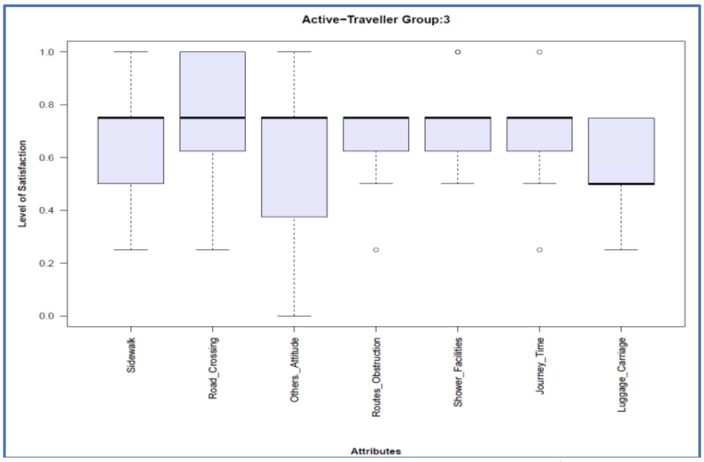

Fig 7:Boxplot for Non-motorisedTravellers' Group 3

Members of the group show dissatisfaction with more attributes of the travel mode than the other two groups. The group members show more dissatisfaction with the *other travellers' attitude*; and some members of the group are not satisfied with the current *sidewalk*, *road crossing*, *route obstruction* and *luggage carrier* situations regarding the non-motorised travel modes.

3.3 Model Design

Fig. 8 is the conceptual overview of the case study provided from the adaptation of the MOSH framework presented in Fig 1. It captures the daily decision process and activities of a traveller on short-distance travel. The motorised travel mode users are typically car users, motorbike users or battery scooters on short-distance journeys

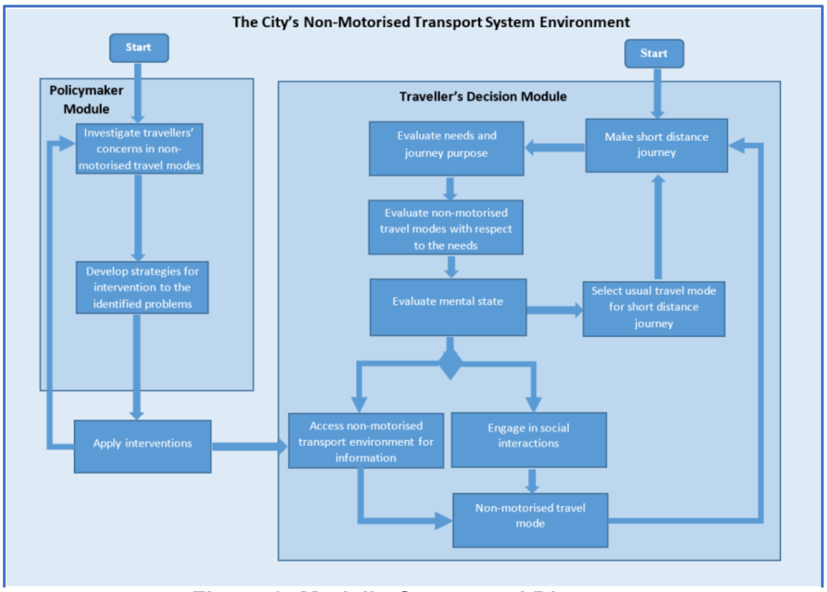

Figure 8: Model's Conceptual Diagram

Travellers (i.e., right box in Fig 8) make a short-distance journey by first evaluating the purpose of their journey (e.g., shopping) as well as their needs regarding the journey (e.g. the need for a luggage carrier). They also consider and evaluate the available non-motorised travel modes and update their mental states to ascertain their satisfaction and certainty levels regarding the travel mode. Travellers' mental status determines the kind of information-seeking strategy to adopt. A traveller can engage in the following four processes depending on the level of uncertainty or satisfaction about the mode:(1) Atraveller with a low uncertainty level will engage in individual processing (i.e., repetition and optimising). (2) when the level of uncertainty is high, a traveller engages in social processing (i.e., imitation and inquiring). (3) when a traveller is satisfied with the preferred mode, it engages in automatic processing without reasoning (e.g., repetition and imitation), and (4) when dissatisfied, a traveller engages in reasoning processing (optimising and inquiring). The choice of a non-motorised mode for a short-distance journey is based on the dynamics of the four factors. The information-seeking process, if successful, may lead to the adoption of any of the non-motorised modes: cycling, walking, skateboarding and scootering after the behavioural change.The policymaker (left box in the figure) here is the County that has the responsibility to investigate why people prefer car travel on short distances that could be easily achieved with non-motorised travel means. From their findings, policymakers formulate policies and develop strategies that are applied as interventions to alleviate travellers' current concerns.

In the modeldesign, the following assumptions were made: 1) Motorised travel mode users have the capability to make use of any of the non-motorised travel modes available. 2) Non-motorised travel mode users do not shift their mode to motorised travel mode. 3) All travellers have abilities to use the available non-motorised travel modes. 4) Each traveller starts the simulation with a preferred travel mode (either motorised or non-motorised). The simplification is that travellersmake use of a chosen travel mode, both, to and from their chosen destination; and the impact of disability is not considered. The simplification is to keep the model simple, while still maintaining satisfactory results and reasonable outputs from the model design.

3.4 Implementation of the Model

The model was simulated in the Recursive Porous Agent Simulation Toolkit (REPAST) Symphony version 2.3.1. REPAST (https://repast.github.io) is a free, open-source, and Java-based simulation toolkit for ABM.

3.4.1 Parameterisation

There are three classes of active objects in the simulation: the Traveller agent, the Travel mode, and the Policymaker. There is one traveller agent class that is capable of using both the motorised and non-motorised modes. During the simulation run, a Traveller agent who started as a motorised travel mode user can switch travel mode to a bicycle and become a cyclist when there are improvements in its perception regarding cycling. Based on the original data collected, all the 740 traveller agents simulated are equipped with two important attributes that are required for the simulation. These are the *preferred mode* attribute which holds the current traveller's travel mode, and the *traveller type* that indicates the description of the traveller (e.g., cyclists, pedestrians, etc.). In terms of demographics, each traveller has a gender, age, preferred travel mode for a short distance, average distance considered feasible with non-motorised travel, and frequency of non-motorised travel usage. In terms of personality, each traveller agent has needs of safe, comfortable travel with health benefits to be satisfied. These needs are the purpose of using the travel mode on their short distance. The needs are determined by the adequacy of the attributes or the concepts of the travel modes which include sidewalk ways/cycle lanes/footpaths, route availability and obstruction-free routes, crossing and road signs at junctions, the attitude of other road users, capability for luggage carrier, shower and other facilities at the destination, as well as journey time consideration. Furthermore, the traveller agent's decision driving factors are:travellers'*ambition* regarding a need, the *needs weight*, *social weight*, *uncertainty*, and *uncertainty tolerance* Each traveller agent starts the simulation with a preferred mode. the traveller's previous experience is set to zero at the beginning of the simulation.

3.4.2 Validation

The credibility and validity of this simulation model were ensured by verifying that the model's algorithms are properly implemented without errors and oversight.

3.5 Experimentation

In the experimentation section, we look into the base scenario and scenarios on two policy interventions. The experimental factors (i.e. the settings that vary between scenarios) are: (a) the demographics of the population, (b) the ratio between motorised and non-motorisedtravellers, (c) policy choice to stimulate travellers'behaviour, (d) traveller's initial preferred travel mode.
The responses observed during the simulation runs are:

A. travellers' mode shift diffusion pattern.
B. travellers' cognitive processing pattern.

The simulation model's runtime is set to one and a half years with 25 replications to account for randomness in the parameterisation process. A warm-up period of 25 days is considered to remove initialisation bias and the mean result of the runs was collected.

3.5.1 Base Scenario

The default run of the simulation as parameterised with the survey data is presented in this section. This serves as the basis against which the impact of the policy interventions is compared.

Travellers' modes shift diffusion pattern

Fig.9 shows the base scenario of the travellers' mode shift pattern that presents the number of travellers in various travel modes.

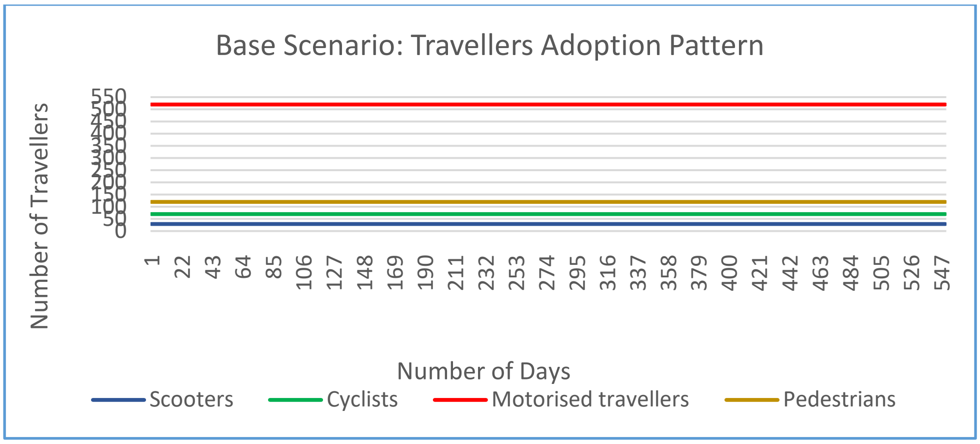

Fig 9: Base Scenario: Travellers' Mode Adoption Pattern

In the Figure, the initial setup values for all categories of travellers (i.e., 520 motorisedtravellers, 120 pedestrians, 70 cyclists, and 30 scooters) did not change throughout the simulation time. This visual observation is expected since there are no interventions applied to stimulate the travellers'behaviours. Therefore, all travellers continue with their usual preferred travel modes.

Travellers' Cognitive Processing adoption pattern

Fig.10 shows the travellers' cognitive processing pattern for the base scenario.

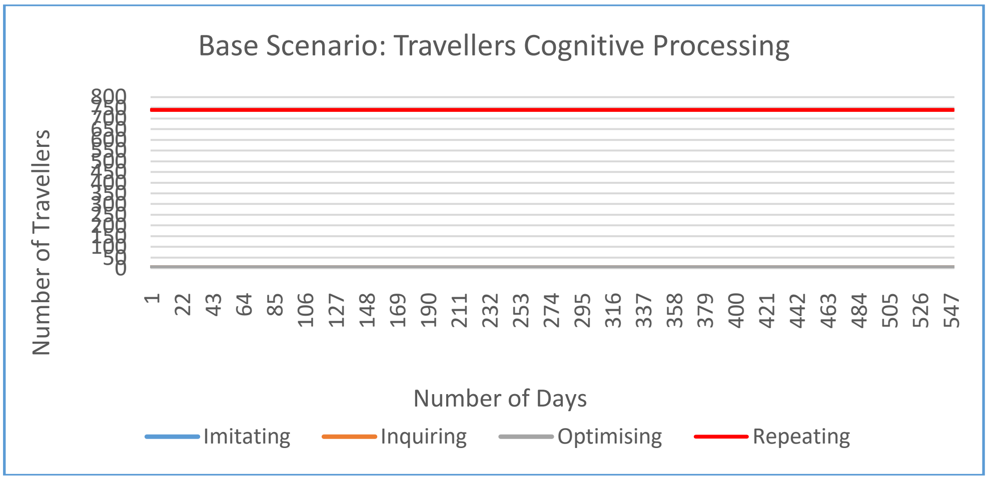

Fig. 10:Base Scenario travellers' cognitive processing

Fig.10 indicates that all 740 travellers engaged in individual cognitive processing of repeating their previous travel behaviours. This is due to the absence of a nudge in the form of policy intervention.

3.5.2 Policy Interventions

The strategies to address travellers' concerns include building relevant infrastructure that supports non-motorised travel, periodic maintenance of the existing infrastructure and policy formulation. Three sets of intervention experiments are performed:

1) Intervention experiment on the four metrics for measuring system performance. Each of the metrics is applied as a single policy regime and the impact are compared.
2) Also, a specific experiment to test the impact of luggage carrier travellers (hard constraint) is considered.

Single policy intervention set of experiment results.

The first single policy intervention scenario experiment targeted comfort and journey-time consideration as shown in Table 2

Table 2. Simulation Parameters for Interventions involving Comfort and Journey-time Scenarios

Travel modes' Intervened areas	Comfort Scenario intervention	Journet-time Consideration Intervention
Provision of continuous link routes.	-	✓
Route availability and campaigns against routes and cycle lane obstructions.	-	✓
provision of crossing facilities and road signs at junctions.	-	✓
Shower and other facilities at the destination.	✓	✓

Travellers' modes adoption pattern with the Comfort and Journey-time Consideration Interventions

The figures present traveller adoption patterns for comfort and journey-time consideration interventions. Fig. 11 (a) presents the time series for the travellers' travel modes adoption in response to comfort intervention and Fig. 11 (b)shows the response to journey-time consideration.

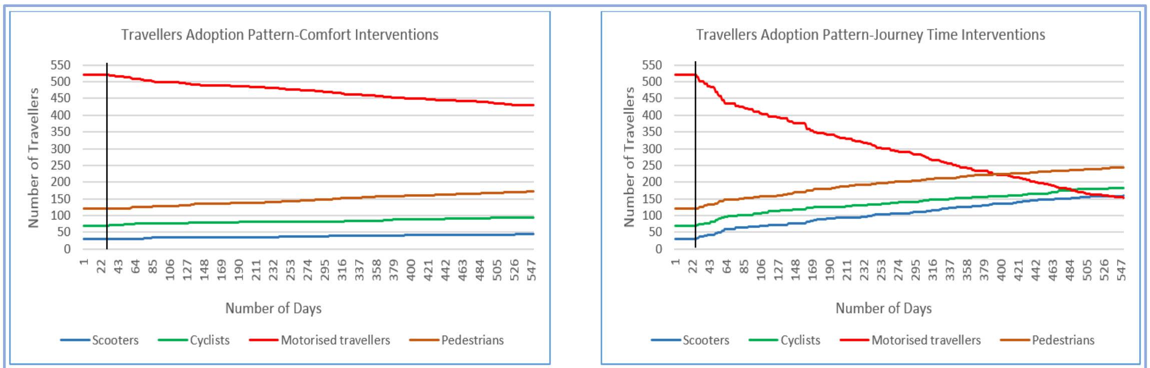

Figure a: Travellers' Non-motorised travel mode adoption pattern: Comfort interventions
Figure b: Travellers' Non-motorised travel mode adoption pattern: Journey -time interventions

Fig 11: Comfort and Journey-time Interventions Mode Adoption pattern

In the explanation for the comfort intervention on the travellers' concerns. It is important to state that the provision and maintenance of showering facilities at the destinations (e.g., workplace) is the only related intervention provided. In Fig. 11(a) the initial steady-state behaviour observed at the beginning of the simulation is due to travellers starting their journeys with their usual travel modes. The back vertical line on day 25 of the simulation indicates the intervention point. There is a gradual decline in the number of motorisedtravellers from the initial value of 540 after the intervention on day 25. This transforms into an observable increase in the number of pedestrians; Cyclists, and Scooters. The reason for the slow adoption behaviour is due to the nature of the intervention provided which is only applicable to travellers to the workplace or education that are concerned with the need to refresh after walking or cycling. Other categories of travellers are less concerned about showering at their destinations.

In Fig 11 (b), The relevant strategies used to stimulate travellers'behaviours in the journey-time consideration intervention includes campaigns against routes and cycle lanes obstructions; provision of continuous link routes, road signs, and crossing facilities. A sharp decline in the number of motorisedtravellers can be observed after the intervention. The reduction in the number of motorisedtravellers transforms into a rise in the number of pedestrians; the cyclist and scooters. It is evident from the series that different categories of non-motorisedtravellers attributed high importance to journey-time factors. Particularly, a 70% increase in the number of cyclists could be attributed to the success of the campaign against routes and cycle lanes obstructions and provision for continuous link routes which makes their journey shorter. Also, pedestrians and scooters find road signs and adequate crossing facilities that are not far from each other significant to their journey time concerns.

Travellers' Cognitive Processing in Response to Comfort and Journey-time Consideration Interventions

Fig 12 (a) and (b) represent the cognitive processing time series for the comfort and journey-time intervention scenarios respectively. The time series in the two graphs indicate that travellers engaged in all cognitive processing strategies (i.e., repeating, optimising, imitating and inquiring). However, the adoption pattern in the two graphs differs in cognitive processing engagements.

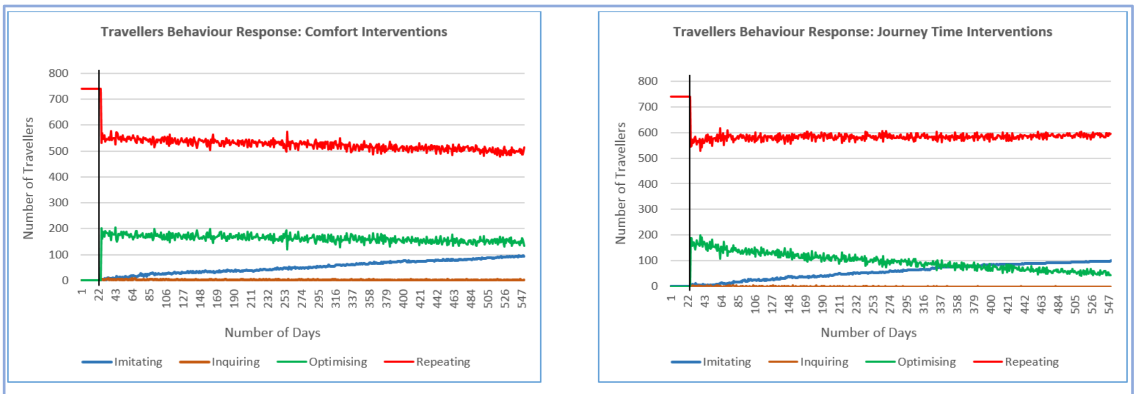

Figure a: Travellers' behavioural response comfort interventions

Figure b: Travellers' behavioural response to Journey-time interventions

Fig 12: Travellers' Cognitive processing for Comfort and Journey-time Interventions

The behaviour in Fig 12 (a) shows that only a few motorisedtravellers rely on inquiring (deep social reasoning), rather, they mostly engaged in observing and imitating various categories of non-motorisedtravellers on the approach to address their comfort concerns. Fig 12 (b) for the journey-time consideration presents slightly a different time series, which includes an initial decline but a constant number of travellers engaging in repeat strategy. This is as a result ofmotorisedtravellers who had adopted either of the three non-motorised travel modes and are satisfied, therefore continued using the adopted modes. In summary, for this scenario, the observable behaviour of travellers in response to interventions indicates that the proportion of travellers affected by a constraint is an important factor to be considered when developing a strategy. This allows the cost-benefit evaluation of the intervention. One insight gained from the scenario is that effort should be expended in developing strategies and providing interventions to the constraints that have a significant impact on the mode choice behaviour of the travellers.

Travel modes adoption pattern with Combined strategic interventions with and without Luggage carrier

Table 3 presents the parameters used in the scenario that represents the impact of combined interventions with all strategies and policies formulated to address the travellers’ concerns.

Table 3. Simulation Parameters for Interventions involving two Scenarios

Travel modes' Intervened areas	Strategies with Luggage Carriers	Strategies without Luggage Carriers
Provision of continuous link routes Sidewalkways/Cycle lanes/Footpaths.	✓	✓
Route availability and campaigns against routes and cycle lane obstructions.	✓	✓
provision of crossing facilities and road signs at junctions.	✓	✓
Campaign against Attitude of road users	✓	✓
Capabilities for luggage carrier	✓	-
Provision of Shower and other facilities at the destination.	✓	✓
Journey time consideration.	✓	✓

In the second column of the table, all the strategies and policies are applied, while the third column presents strategies that exclude provision for luggage carriers in the non-motorised travel modes.The scenario is to investigate how the luggage carrier influences non-motorisedtravellers' mode's adoption differently from when it is not included.

Fig 13 shows the travellers' mode adoption time series in response to interventions with and without luggage carriers. Figures 8 (a and b) present the time series for the two scenarios respectively. The vertical purple line in the figures indicates the intervention point.

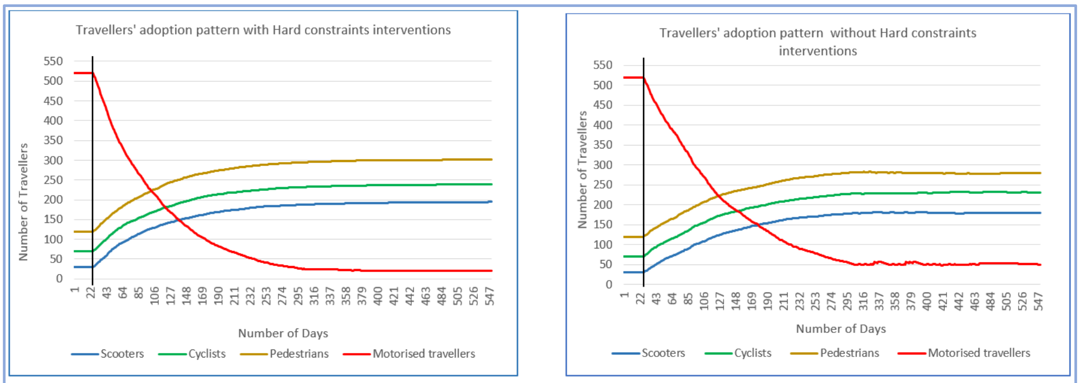

Figure a: Non-motorised travel mode Adoption pattern for all interventions

Figure b: Non-motorised Adoption pattern for all interventions without hard constraints

Fig 13: Motorised to Non-motorised Modes Adoption Response to Combined Interventions

In Fig 13 (a) and (b), The travellers' adoption patterns in both scenarios show a very similar trend curve. The scenario in Fig 13 (a) that included luggage carrier intervention has a quick response to the interventions at the early stage of the simulation by producing a smooth deeper curve than the scenario in Fig 13 (b) that did not include luggage carrier intervention. The deep curve diffusion of motorisedtravellers transforms to a rise in various categories of non-motorised travel modes usage. The observable behaviour of the graph can also be attributed to early social interactions among the travellers in Fig 13 (a) than in Fig 13 (b), and the importance traveller attached to the conveniences of Luggage carriage on short-distance travels.

Travellers Cognitive Processing behaviour pattern with Combined strategic interventions with and Without Luggage Carrier

Fig 14 presents the travellers' cognitive processing behaviours for the adoption patterns depicted in Figure 13 (a and b). The two graphs in Figure 14 also show a very similar trend before the intervention on day 25.

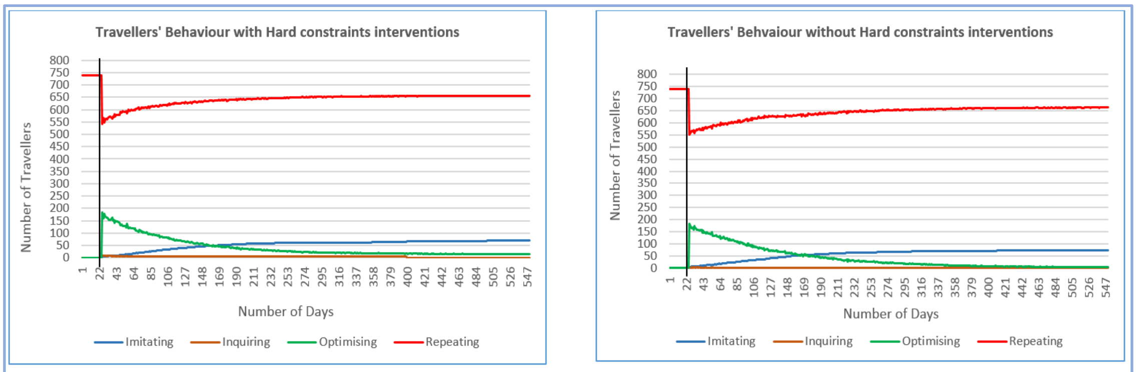

Figure a: Travellers' behavioural response to all interventions including hard constraints

Figure b: Travellers' behavioural response to all interventions without hard constraints

Fig 14: Travellers' Cognitive Processing in Response to Combined Interventions

The behaviours are also the same after the intervention except for the variations in the time that the respective decision strategies take place and also the differences in the number of travellers involved in the processing behaviours in the two scenarios.In Figure 14(a and b), after the intervention, manytravellers started engaging in *optimising strategy* (i.e., individual reasoning). This account for the initial decrease in the number of travellers engaging in repeating strategy (i.e., travellers who are both satisfied and certain about their chosen modes). The trend slows down steadily as more motorisedtravellers get involved in *imitating* and *inquiring strategies* (i.e., social interactions) with the existing non-motorisedtravellers. With the emergence of travellers engaging in *imitation* and *inquiring strategies* and a steady increase in the number of travellers engaging in *repeating strategy*, the number of travellers engaging in optimising strategy approached zero. Although, the number of travellers engaging in *inquiring strategy* is low compared to the number of travellers*imitating* others. This can be attributed to the proportion of travellers that are both *uncertain* and *dissatisfied* with their travel modes as well as those that considered non-motorised travel to be practically impossible to meet their needs.

4. DISCUSSION

Some important insights are observed from the scenarios, these include the difficulties in providing 'luggage carrier' interventions on non-motorised travel modes which reduce substantially the potential for increasing these travel modes for everyday journeys. This affirms the submissions of Pooley *et al.* (2011) on the effect of a luggage carrier on non-motorised travel modes. Although Pooley *et al*. (2011) study used static descriptive data without considering the influence of social interactions among travellers. Also, in this study, the impact of social interactions contributed to a shift in non-motorised modes' adoption as demonstrated by the rise in the number of travellers engaging in *repeating strategy*. The reason is that travellers engage themselves in different active journeys and purposes (e.g., work, visit) most of which require less luggage carriage. Hence, a motorisedtraveller that has similar journey features as a non-motorisedtraveller could be influenced through interactions to choose a non-motorised travel mode. It is also evident that a proportion of motorisedtravellers do not change their behaviour. It could be that the use of non-motorised travel is practically not feasible for these sets of travellers due to their locations or needs. However, there is a likelihood of more travellers adopting non-motorised travel if the policymaker directs the interventions attention to other aspects of non-motorisedtravellers' concerns other than the 'luggage carrier'. Another insight is that there is evidence of interdependency among system components as a result of the interplay between ergonomic factors and psychological factors. For instance, the obstruction-free routes and maintenance of walkways interventions to address journey-time considerations in Fig 13 (b) contributed to the resolution of the travellers' safety and convenience constraints to some extent. However, this finding needs further investigation with scenarios that include different interventions in future. Also, there is a need for further experimentations regarding the duration of applied intervention, there is the possibility of duration playing a significant role in response to interventions.

5. CONCLUSION

This paper investigated how both ergonomics and psychological factors within the non-motorised travel environment impact the travellers' decisions to travel with the modes that require more physical abilities on their short-distance journeys. The modelling process gave insight into the kind of interventions that can stimulate changes in travellers'behaviours to adopt non-motorised travel. An agent-based social simulation framework named MOSH was used to model the behaviour of both motorised and non-motorised travellers in the City of Nottingham. The outcome of the investigation provides policymakers with insights into factors including ergonomics, psychological and other factors that need to be considered while providing interventions to stimulate motorisedtravellers'behaviour towards the adoption of non-motorised travel.

Although, there are limitations in exceptional cases including where traveller'sbehaviour might be practically impossible to stimulate due to the nature of their journeys (locations or needs) in the framework. Also, conveniences related to luggage carrier which is considered hard constraints to remove could be achieved by applying suggested travel solutions such as factory fixing of extension.

ACKNOWLEDGEMENTS

The authors deeply appreciate the Nigeria Tertiary Education Trust Fund (TETFund) for providing the first author (OTF) a Phd funding toward this work.

REFERENCES

A, B. G., A, S. F., B, T. S., & C, R. F. (2010). *The co-benefits for health of investing in active transportation*. *21*, 122–127.

Bonabeau, E. (2002). Agent-based modeling: methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences*, *99*(suppl. 3), 7280–7287.

Cornelissen, M., Salmon, P. M., McClure, R., & Stanton, N. a. (2013). Using cognitive work analysis and the strategies analysis diagram to understand variability in road user behaviour at intersections. *Ergonomics*, *56*(5), 764–780.

Davison, L., & Curl, A. (2014). A transport and health geography perspective on walking and cycling. *Journal of Transport and Health*, *1*(4), 341–345.

Faboya, Olusola. T, Siebers, P.-O., Ryan, B., & Figueredo, G. P. (2018). How do Travellers Decide: A Stochastic Modelling Approach to Determine Decision Factor Significance. *Proceedings of the European Modelling and Simulation Symposium*. Budapest.

Faboya, Olusola T, Ryan, B., Figueredo, G. P., & Siebers, P. (2020). Computers & Industrial Engineering Using agent-based modelling for investigating modal shift : The case of university travel. *Computers & Industrial Engineering*, *139*(September 2019), 106077.

Faboya, Olusola T, Siebers, P., Ryan, B., & Figueredo, G. P. (2017). A Novel Modal Shift Modelling Framework for Transport Systems. *Proceedings of the 13th Annual Conference of Social Simulation*. Dublin.

Faboya, Olusola Theophilus. (2020). *The Use of Computer Science Practices and Methods for Developing Social Simulations to Stimulate Changes in Travellers ' Mode Choice* (University of Nottingham, United Kingdom). University of Nottingham, United Kingdom.

Flache, A., Mäs, M., Feliciani, T., Chattoe-Brown, E., Deffuant, G., Huet, S., & Lorenz, J. (2017). Models of social influence: Towards the next frontiers. *Jasss*, *20*(4).

Gantner, A., & Kerschbamer, R. (2018). Social interaction effects: The impact of distributional preferences on risky choices. *Journal of Risk and Uncertainty*, *56*(2), 141–164.

Gardner, B., & Abraham, C. (2007). What drives car use? A grounded theory analysis of commuters' reasons for driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *10*(3), 187–200.

Gehlert, T., Dziekan, K., & Gärling, T. (2013). Psychology of sustainable travel behavior. *Transportation Research Part A: Policy and Practice*, *48*, 19–24.

Holland John. (2006). Studying complex adaptive systems. *Journal of Systems Science and Complexity*, *19*(1), 1–8.

Jager, W, & Janssen, M. (2012). An updated conceptual framework for integrated modeling of human decision making: The Consumat II. *Eccs 2012*, 10.

Jager, Wander. (2000). Formalising the conceptual model. *Modelling Consumer Behavior*, 101–116.

Macal, C. M., & North, M. J. (2009). AGENT-BASED MODELING AND SIMULATION. In A. D. and R. G. I. M.D. Rossetti, R.R. Hill, B. Johansson (Ed.), *Proceedings of the 2009 Winter Simulation Conference* (pp. 86–98).

Manaugh, K., & El-Geneidy, A. M. (2013). Does distance matter? Exploring the links among values, motivations, home location, and satisfaction in walking trips. *Transportation Research Part A: Policy and Practice*, *50*, 198–208.

Mann, E., & Abraham, C. (2006). The role of affect in UK commuters' travel mode choices: An interpretative phenomenological analysis. *British Journal of Psychology*, *97*(2), 155–176.

Naikar, N., Moylan, A., & Pearce, B. (2006). Analysing activity in complex systems with cognitive work analysis: concepts, guidelines and case study for control task analysis. *Theoretical Issues in Ergonomics Science*, *7*(4), 371–394.

Naikar, Neelam. (2006). An Examination Of The Key Concepts Of The Five Phases Of Cognitive. *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting-2006*, 447–451.

Naikar, Neelam, Treadwell, A., & Brady, A. (2014). *Cognitive Work Analysis Beyond Human Factors and Engineering : Application to Military Doctrine and Strategy Development*. 330–334.

Oughton, E. J., Usher, W., Tyler, P., & Hall, J. W. (2018). Infrastructure as a Complex Adaptive System. *Complexity*, *2018*, 1–11.

Pooley, C., Jones, T., Horton, D., Jopson, A., Mullen, C., Chisholm, A., & Constantine, S. (2011). *Understanding Walking and Cycling: Summary of key findings and recommendations*. Lancaster.

Rasmussen, J., Pejtersen, A. M., & Goodstein, L. P. (1994). *Cognitive systems engineering*. Wiley.

Roberts, J., Popli, G., & Harris, R. J. (2017). Do environmental concerns affect commuting choices?: Hybrid choice modelling with household survey data. *Journal of the Royal Statistical Society. Series A: Statistics in Society*.

Sommerville, I. (2016). *Software Engineering* (10th ed.). Essex: Pearson Education Limited.

Stanton, N. A., McIlroy, R. C., Harvey, C., Blainey, S., Hickford, A., Preston, J. M., & Ryan, B. (2013). Following the cognitive work analysis train of thought: exploring the constraints of modal shift to rail transport. *Ergonomics*, *56:3*(July 2015), 522–540.

Vicente, K. J. (1999). *Cognitive Work Analysis Toward Safe , Productive , and Healthy*.