The Use of Computer Science Practices and Methods for Developing Social Simulations to Stimulate Changes in Travellers' Mode Choice

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Publications

This section presents a list of publications formed as part of the research work for this thesis.

1. Faboya, O.T., Siebers, P.O., Ryan, B., Figueredo, G.P. (2020). Using Agent-Based Modelling for Investigating Modal Shift: The case of University Travel. *Computer and Industrial Engineering*.

2. Faboya, O.T., Siebers, P.O., Ryan, B., Figueredo, G.P. (2018). How do Travellers Decide: A Stochastic Modelling Approach to Determine Decision Factor Significance. *The European Modelling and Simulation Symposium (EMSS'* 2018). Budapest, Hungary.

3. Faboya, O.T., Siebers, P.O., Ryan, B., Figueredo, G.P. (2018). Position Paper: The Usefulness of Data-Driven, Intelligent Agent-Based Modelling for Transport Infrastructure Management. *IEEE International Conference on Intelligent Transportation Systems*. Hawaii, USA.

4. Faboya, O.T., Siebers, P.O., Ryan, B., Figueredo, G.P. (2017). A Novel Modal Shift Modelling Framework for Transport Systems. *The 13th Annual Conference of Social Simulation*. Dublin, Ireland.

Abstract

In this thesis, Computer Science practices and methods including Software Engineering and Artificial Intelligence techniques are explored to incorporate Human Factors and Psychology knowledge in a structured way into agent-based models to model modal shift in a social system. Observations of peoples' behaviours in social systems regarding choice-making suggest that they tend to have preferences among the available alternatives in many situations. Experts in the domain of Psychology have been interested in the relationships that exist between the psychological processes (factors) and peoples' behaviours. Human Factors' experts are concerned with, among other things, the study of factors and development of tools that improve users' experiences. The findings from the literature suggest that the two groups have been working from the perspective of their domains without much collaboration. Also, no known framework or methodology offers the required collaborative modelling support and techniques to model people's emotion as they traverse the system.

The aim of this thesis is, therefore, to provide modelling techniques that better support the use of Human Factors and Psychology knowledge in understanding factors that influence travellers' decision-making in travel mode choice so as to stimulate changes in their behaviours. The support also provides collaboration among relevant stakeholders to work on modal shift project in the transport system.

The method adopted in carrying out the research reported in this thesis is informed by the descriptive, developmental, and exploratory nature of the objectives of the research. Our novel methodology which includes a framework is named MOdal SHift (MOSH) methodology. Its development process involves the use of design principles that include encapsulation, data abstraction, inheritance, and polymorphism in defining and integrating the Human Factors and Psychology practices into the methodology. The structures and behaviours of the system components are described and documented using the Unified Modelling Language (UML) as a standard specification language to promote uniform communication among a group of experts. The decision variable decomposition module and techniques for deriving travellers' emotions that correspond to their context involved the use of the Fuzzy sets system. The methodology contains guides that include the process map diagram showing the major stages in the methodology as well as the step-by-step development guidelines.

To verify and to validate the methodology, two case studies in the transport domain are selected. The first case study aims at demonstrating the use of the framework included in the methodology for policy formulation. The second case study has the goal of demonstrating the use of the methodology for understanding individuals' abilities to satisfy travel requirements. Data Science methods including both supervised and unsupervised learning algorithms are applied at relevant stages of the case studies.

The reflection from the cases investigated with the MOSH methodology reveals its novelty in modelling interdependencies among the transport system's constraints and in modelling travellers' emotional state as they traverse the transport system's environment. In addition, the adoption of the standard specification language in the design of the methodology provides the means for easy communication and transfer of knowledge among stakeholders.

The use of Software Engineering tools and methods in conjunction with the agent-based modelling paradigm in the MOSH methodology design and development phases promotes the separation of concerns for the interrelated and non-linear levels of organisation within a sociotechnical system. It also promotes extensibility of various aspect of the methodology as a result of the independence among the components and makes reusability of relevant aspects possible when there are needs to use the same functionality in a new project. The agent-based modelling paradigm provides opportunities for investigating the interactions among the agents and the environment as well as providing insights into the various complex interrelated behaviours.

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List of Abbreviations

ABM	Agent-Based Modelling
ABMS	Agent-Based Modelling and Simulation
ABSS	Agent-Based Social Simulation
ACT-R	Adaptive Control of Thought-Rational
AH	Abstraction Hierarchy
AOSE	Agent-Oriented Software Engineering
ANN	Artificial Neural Network
BDI	Belief Desire and Intention
CAS	Complex Adaptive System
CI	Computational Intelligence
CMA	Circumplex Model of Affect
ConTA	Control Task Analysis
CW	Computing with Words
CWA	Cognitive Work Analysis
EABSS	Engineering Agent-Based Social Simulation
ECS	Efficiency, Comfort and Safety
GA	Genetic Algorithm
GAIA	Generic Architecture for Information Availability
HF	Human Factors
IBM	Individual-Based Model
IDE	Integrated Development Environment
IODA	Interaction-Oriented Design Agent Simulations
MAIA	Modelling Agent System based on Institutional Analysis
MASON	Multi-Agent Simulation Of Neighbourhoods/Networks
MDP	Markov Decision Processes
MOSH	MOdalSHift
ODD	Overview, Design concept and Details document protocol

OO	Object-Oriented
OOAD	Object-Oriented Analysis and Design
PCA	Physical, Cognitive and Affective
PCA-AH	Physical, Cognitive, and Affective-Abstraction Hierarchy
PDT	Prometheus Design Tool
PECS	Physical Emotional Cognitive and Social
PSY	Psychology
REPAST	Recursive Porous Agent Simulation Toolkit
SE	Software Engineering
SOAR	State Operator and Result
STS	Socio-technical System
SODA	Societies in Open and Distributed Agent spaces
UML	Unified Modelling Language

1 Introduction

In our everyday lifestyle, we all have to make individual decisions and choose from alternatives in various aspects of life. Decisions such as the kind of pizza to order, the neighbourhood to live, the health care services to access, the career to pursue, the travel mode for our journeys, etc., are examples of daily scenarios requiring human decision-making. In some of these situations, decisions are made frequently as it happens in our daily choice of travel modes; in other situations, it occurs less frequently. In decision-making generally, people consider many factors concerning their needs, the purpose of the needs, their abilities, etc. These factors involve psychological and ergonomic aspects as well as the activities that people can perform in various situations within the system. People also consider among other things, the system's environment, quality and prospect of the alternatives involved and uncertainties surrounding the decision processes.

People tend to have a preferred choice among available alternatives when the decision occur over time and when the set of brands involved offer the same functional purpose. Preferences in people are the expectations, likes, dislikes and inclinations that drive their decisions which come as a result of peoples' taste and influenced by peers, these preferences are not fixed (Simonson, 1989). Several works including Gantner & Kerschbamer (2018) and Flache *et al.* (2017) have shown that social interaction drives a decision-maker to make his choice dependent on what he observes others in his reference group do. In any system where decisions are made, if it occurs that a larger percentage of the population have preferences for one product among the available alternatives, there is a likelihood of uneven distributions in the shares of respective brands. Also, when situations involve social systems, the impact of such a decision could be significant on various aspect of the system. For instance, it could result in the challenges of over (or under) utilisation of facilities in the system. A social system that includes technical aspects, operational processes and people who use and interact with the technical system is generally referred to as Sociotechnical system (Sommerville, 2016). The complexity of the interrelated components of such a system makes the understanding of the causes of peoples' preferences a difficult issue.

The domains of Human Factors (HF) and Psychology (PSY) have been concerned with the factors that influence people to behave the way they do in a social system. HF experts typically focus on the study of factors and development of tools to facilitate the achievements of enhancing performance, increasing safety and user satisfaction (Vicente, 1999; Wickens *et al.,* 2004) within a system environment. Psychologists deal with the relationship between psychological processes (which has to do with factors that influence behaviour) and the behaviour of users (Lichev *et al.*, 2017). However, approaches to investigating people's behaviour in choice-making from the two domains of knowledge have been from the perspectives of the respective disciplines. It is believed that the cross of ideas among the two groups could benefit research on the improvement of users' experience in sociotechnical systems.

1.1 Motivation

The initial motivation for this research is to incorporate HF and PSY knowledge into modelling modal shift problem in the sociotechnical transport system so that relevant domain knowledge can be expressed in stimulating travellers' mode choice behaviours. Currently, there are communities of users already applying Computer simulations to investigate factors that influence people's behaviours from the two disciplines. There are also several works involving transport psychologists and computational modellers focusing on investigating the impacts of the factors on travellers' mode choice, however, there has been no common ground for collaboration and exchange of ideas that can promote the development and support for the ongoing research in the area.

Although, there are numerous existing development frameworks that can be used to model human decision-making process. These include the generic Agent-Oriented Software Engineering (AOSE) framework family which has a different focus from modelling decision process that can lead to a change in behaviour. Some of these existing AOSE frameworks for disaggregate entity modelling cannot model the dynamic, unanticipated and uncertainty features that can be found in typical sociotechnical system environments. Therefore, the application of such development frameworks in stimulating traveller's behaviour for a modal shift in transport system will be inadequate as they fail to address issues related to social and psychological nature of the travellers. In addition, they fail to address the influence of travellers' contexts (temporal and spatial) as they traverse the environment on their behaviour. Thus, at present, no known single methodology offers a platform on which interested stakeholders and modellers from relevant disciplines can collaborate to work on problems related to improving travellers' experiences in an adaptive and dynamic transport environment. None also offers a technique for stimulating their behaviour.

Computer Science, however, and here in particular Software Engineering (SE), offers many tools and techniques that allow a collaborative structured approach to software development, with well-defined processes supporting system analysis and software design. These processes use tools such as Unified Modelling Language (UML) to support engagement with clients. The UML defines the language only (Priestley, 2003), it will therefore, be appropriate for providing a consistent and standard defined notation for the object-oriented method used in the design that promotes collaborations. The design structure that adopted object analysis and design arrangements will provide easy maintenance, team-work package, communication, and modularisation at the development stage. Moreover, Artificial Intelligence (AI) offers functionalities to mimic people real-life behaviour. The Fuzzy set in addition to other Data science methods including classification and data mining algorithms handle knowledge discovery from the huge volumes of interdependent data arising from people's activities and operations within the system.

Furthermore, the theory that guides sociotechnical system is based on the idea that the design and performance of any organisational system can only be understood and improved if both 'social' and 'technical' aspects are brought together and treated as interdependent parts of a complex system. Baxter & Sommerville (2011) observe that a sociotechnical approach to system development leads to a better understanding of how human, social and organisational factors affect the ways that work is done, and technical systems are used. Such understanding would assist in identifying the constraints on the actors' operations in the system, and how the insight gained could be explored to stimulate their behaviours for better performance. Therefore, the process of understanding the operations and interactions of a sociotechnical system's components can benefit greatly from the idea of a complex adaptive system (CAS) (Holland, 2006). 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).

Traditionally, whenever there is a new approach to solving a problem or whenever there is a need to test the applicability of a new approach, model representation has been one common way of gaining insight into such situations. Models provide a better understanding of the operations and activities within the system under investigation. Shannon (1975) describes a model as a representation of an object, system or idea in some forms other than that of the entity itself. In modelling CASs, Bonabeau (2002) argues that Agent-Based Modelling (ABM) is a suitable computational method. ABM provides a better way of representing an individual 'agent' with varying attributes, modelling of context-dependent action and implementing qualitative behaviour rules (Macal & North, 2009). An agent is an autonomous decision-making unit with diverse characteristics. An emerging aspect of ABM that is concerned with the simulation of social phenomena, using computer-based multi-agent models is referred to as the Agent-Based Social Simulation (ABSS). Both the ABM and the ABSS allow the representation, experimentation and analysis of complex social phenomena to gain an understanding of the dynamics behind the behaviour of the system's components. (Elsenbroich & Verhagen, 2016).

For the achievements of purpose, in this research, SE tools and methods, as well as relevant AI techniques, are explored to incorporate HF and PSY knowledge in a structured way into the ABM to provide support for developing a platform where stakeholders from a different background can:

1) Collaborate to work on a problem.
2) Conceptualise and model problems that involve behaviour change in product choice.
3) Build a model and analyse the outputs of the simulation model.

In line with the initial motivation, the following discussions focus on travellers' mode choice in transport system.

The motivation comes from the current challenges due to over-dependency on private car use in our society. At the individual level, transport plays a role in the choice of where to live, work or shop. With the increase in population and as the demands for the mobility need increases, the resultant effects of individual travellers' lifestyles is characterised by challenges that include environmental, social, health, economic, and land use among others (Steg, 2003; Heath and Gifford, 2002; Nurdden *et al.*, 2007, Chapman, 2007; Graham-Rowe *et al.,* 2011). Despite the identified challenges, Chapman (2007) and Stanton *et al*. (2013) observe that transport sector remains the fastest growing, with car travel alone constituting more than three-quarter of all vehicle kilometre travelled (Graham-Rowe *et al.*, 2011).

In view of the aforestated challenges, experts in the transport industry including IPCC (2008) and Derek Halden Consultancy (2003) have earlier suggested modal shift on the part of individuals as one possible option to mitigate various car travel challenges. In transport system, the modal shift is said to occur when a transport mode has a comparative advantage in a similar market over another mode, and the mode with an advantage attracts more users than the other (Rodrigue, 1998). A modal shift can be achieved through a behaviour change in travellers' usual travel mode choice and usage (Chapman, 2007; Steg, 2007). Behaviour change can also be strongly influenced by a change in the users' experiences which has been the focus of HF and the PSY.

However, there are several existing travel mode choice studies including An *et al.* (2011), Jha *et al*. (1998) and Nurdden *et al.* (2007) that address specific problems. There are also generic development frameworks such as the Four-stage models (Mcnally, 2007), and Activity-based travel demand model (Ben-Akiva and Bowman, 1998) that guide users to model different specific problems.

The existing model development frameworks have the following limitations in their capabilities to model modal shift in transport system:

1) Inability to analyse the dynamics of the travellers as they traverse the transport system environment.
2) There is no consideration for standard language that can promote better communication among collaborators.
3) Inability to model travellers' emotional perception at various stage of their journey in as they traverse the transport environment.
4) Limited behavioural theories in the reasoning architectures of the few available disaggregate models inhibit the range of behaviours that can be modelled.
5) They are predominantly mathematical models that are intractable for non-experts when used to model individuals with diverse attributes engaging in social interactions.
6) They are primarily system-level aggregate models that focus on the proportional behaviour of the population rather than on the individual travellers' behaviour in an environment.

Taking into account the gaps identified, a methodology that can be used to conceptualise the dynamics of travellers' context (spatial and temporal) as well as capture their emotional state as they traverse the transport system's environment is required.

1.2 Research Aim and Objectives

This research aimed at developing a modal shift simulation study methodology that makes use of SE tools and methods together with AI techniques in a novel way that incorporates HF and PSY knowledge into ABM so as to:

(a) Allow domain knowledge regarding a specific human-decision problem to be embedded into the modelling process in a structured way.
(b) Provide co-creation support for collaborations among interested experts.
(c) Provide support for stakeholders to understand, conceptualise, build and employ relevant simulation models on travellers' mode choice decisions.
(d) Provide analytic support to understand individuals in a dynamic system.

In order to achieve the aim of the research, the following objectives are set to be accomplished:

1. To critically review the literature on the fundamentals of traveller's mode choice process; human factors, social and psychological theories of human behaviour, as well as the factors that influence behaviour change of travellers so as to understand the process involved and to identify possible constraints.
2. To construct a model development framework that allows embedding HF and PSY knowledge into conceptualising travellers' mode choice process through the knowledge gained from the review and initial surveys.
3. To apply SE and AI methods and tools to assist in designing templates for the key components of the system.
4. To develop a methodology that defines a study life cycle that allows the development and use of the models in a structured way.
5. To validate, verify and evaluate the effectiveness of the framework and methodology using two case studies on travellers' operations and processes in travel mode choice to address the following aspects:
    i) strategic policy formulation, and
    ii) real-word implementation that demonstrates the understanding of factors that determine individual travellers' decisions.

Consequently, this research seeks to answer the following questions:

- How can Computer Science practices and methods assist stakeholders (experts and modellers from other disciplines) to apply HF and PSY knowledge better in modelling modal shift in travellers' mode choice?
- How can Computer Science practices and methods assist stakeholders to build models that answer specific modal shift questions in travellers' mode choice?
- To what extent can SE and AI methods and tools assist in the development of a methodology that provides collaborative supports for experts from different backgrounds?
- How can the ABM paradigm coupled with SE practices and AI techniques assist stakeholders to gain insights into understanding travellers' decision factors in travel mode choice?

1.3 Research Contribution

The main contribution of this research to the body of knowledge is a novel modal shift framework for modelling travellers' travel mode choice, which is embedded into a modal shift methodology, defining a structured approach for the study life cycle. The methodology, amongst others, consists of the following novel elements:

(a) An algorithm for generating traveller's affective display from the survey data.
(b) An algorithm for the decomposition of travellers' decision components into their constituent parts with the capacity to identify the significance of each constituent part.
(c) Reusable and easy to extend libraries that support collaborative model development process by incorporating HF and PSY domain knowledge in a structured form into modelling travellers' mode choice process.

For the first time, this research combines knowledge from two principal disciplines with Computer Science practices to address personality, uncertainty and other system factors that determine travellers' decisions in travel mode choice. The methodology informs the development of a framework to support stakeholders in conceptualising the elements of the travellers' mode choice process holistically. The idea is to provide potential supports to analyse individual travellers context in a dynamic transport system and to understand interactions among travellers so as to stimulate their behaviour.

1.4 Thesis Structure

The structure of this thesis is as follows:
Chapter 2 presents the review of related literature that focuses on relevant topics including Human behaviour in products choice, the models of travellers' behaviour in travel mode choice, the sociotechnical systems, complex adaptive systems, agent-based modelling, and survey of agent-oriented modelling techniques and the gaps in the existing development frameworks and methodologies. Chapter 3 discusses the research design that includes the strategy employed in the research, the overview of examples in travellers' modal shift problems, the requirements for the framework and the methodology development, and the details of the chosen tools and methods for the framework and the methodology development. Chapter 4 presents the Modal Shift framework, its description and development principles; and reflections on the novelty of the framework. Chapter 5 presents the Modal Shift Methodology and the process map with the description of the methodology stages. A Case study that tested the credibility of MOSH methodology to support stakeholders in policy formulation developments is presented in Chapter 6. Chapter 7 reports another case study that demonstrated the effectiveness of MOSH methodology to investigate individual travellers' response decision factors in mode choice. Chapter 8 presents the conclusions, a summary of the research, discussions arising from the research, the contribution to knowledge as well as limitations and future directions for this research.

2 Literature Review

This chapter presents the survey of the fundamentals of human behaviour in product choice in Section 2.1, and the models of travellers' mode choice behaviour in Section 2.2. Section 2.3 discusses the nature of travellers' mode choice system. The sociotechnical system and complex adaptive system concepts are introduced in Sections 2.4 and 2.5 respectively. Section 2.6 reviews the survey of modelling techniques. Agent-based modelling and simulation as well as agent-based social simulation are discussed in Sections 2.7 and 2.8 respectively. The survey of existing agent-oriented models development frameworks is presented in Section 2.9. After reviewing the existing development frameworks, the research gaps are introduced in Section 2.10. From the gaps, the potentially relevant tools and methods for the proposed framework and methodology including language specification approaches are surveyed in Section 2.11. The chapter ends with a summary of the findings in the literature in Section 2.12.

Figure 2.1 summarises the outline of this chapter.

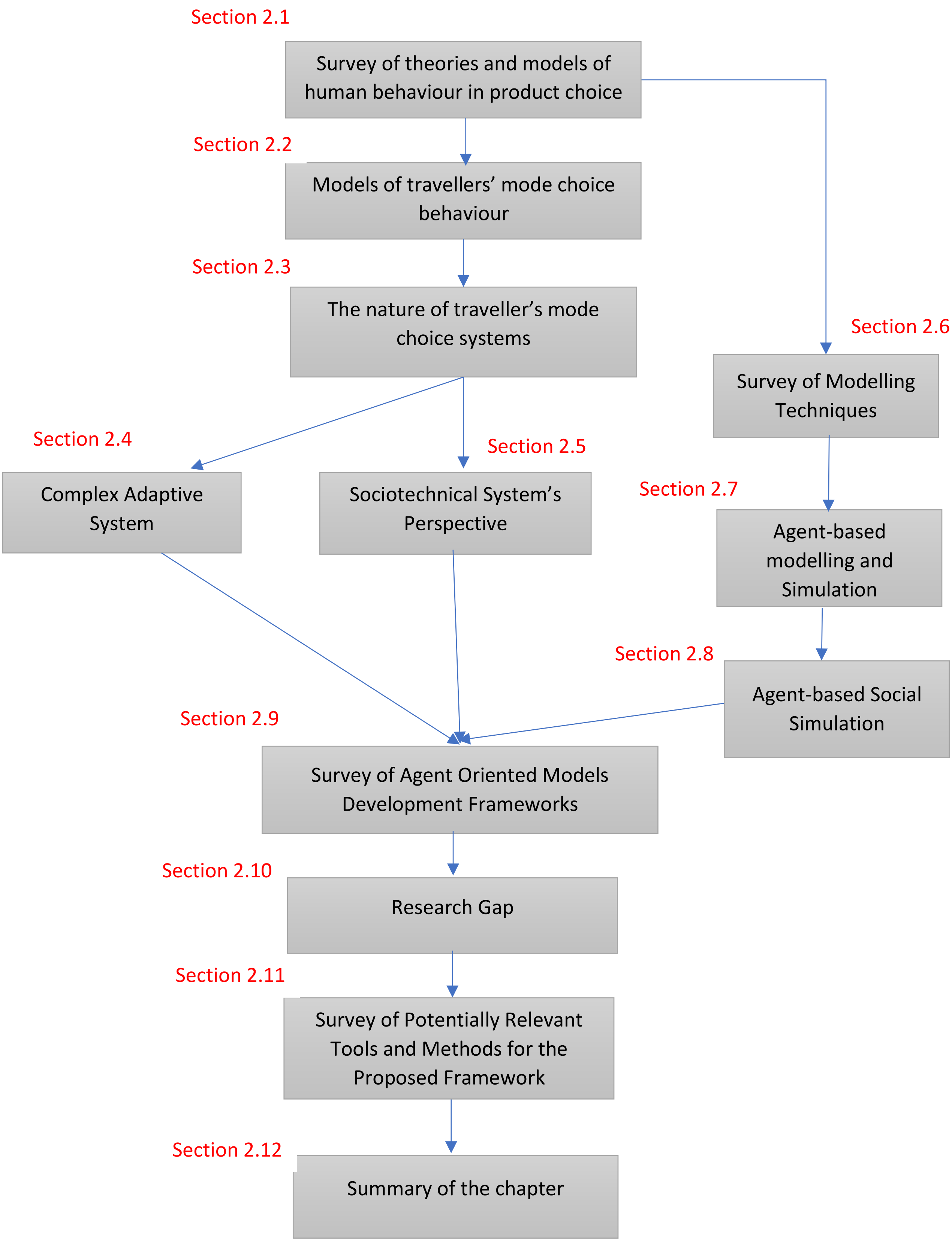

Figure 2.1: Outline of the Literature review Chapter

2.1 Theories and Models of Human Behaviour in Product Choice

Human decision-making process in product choice has attracted considerable research interests. From a marketing point of view, Perner (2006) describes customers' behaviours as "the psychology of how they think, feel, reason, and select between different alternatives like brands, products, and retailers". Computational modelling works including:

- Amstutz (1967) microanalytical model of consumer behaviour in brand choice;
- Howard & Sheth (1968) theory of buyers' behaviour; and
- Sheth *et al*., (1991) theory of consumption values

focussed on the factors that influence human behaviours in products choice and explained the fundamental processes involved in choosing among alternatives. The paragraphs below expand more on these theories and models.

A simplified form of the Amstutz (1967) microanalytical model explains that consumers first define the attributes they seek in a product, having an "ideal" product in mind, based on the occasion for which it is intended and, on the consumer's personal preferences. They also form a perception of the characteristics of each available alternative, which is open to modification through information-seeking activities. Alternative brands are then matched against the "ideal". The consumers then purchase the brand which best meets or exceed their requirements. If no brand matches the "ideal", consumers will either change their requirements or refuse to proceed with the purchase. The Amstutz model explicitly identifies the processes that consumers take in choosing their preferred products.

Howard & Sheth (1968) theory of buyer behaviour explains that buying behaviour is more or less repetitive, and the buyer establishes purchase cycles for various products which determine how often he will buy. For some products such as durable appliances and travel modes, this cycle is lengthy, and the purchase is infrequent. For many other products such as food and travel mode usage, the purchase is short and frequent. Confronted by the choice decisions, the consumer simplifies his task by storing relevant information and establishing a routine in his decision process. In summary, the theory of buyer behaviour assumed that the brand choice process is systematic rather than random. Therefore, the process can be observed in certain standard ways. They also assume that consumer's behaviour is rational within the limits of his cognitive and learning capacities and within the constraints of limited information. However, the theory is not completely normative but a positive theory with no possibilities of doubt or uncertainties; and the behaviour that can be observed in the system is caused by stimuli, either in consumers or in the consumer's environment. Although this theory presents consumers as rational and does not follow a normative approach, which might not represent a typical consumer's behaviour in an adaptive system, it does recognise the importance of a consumer's environments within which the decision is taken. It also recognises information seeking as a key component and factor that is important in making decisions.

In another work, Sheth *et al.* (1991) theory of consumption values identifies the factors that influence individual choices. The theory gives insight into why consumers choose one product type over another and relate the theory to choices involving a full range of product types (e.g., consumer nondurables, consumer durables, industrial goods and services etc.). Five important consumption values are identified (depicted in Figure 2.2) to explain why consumers choose a product and not the other.

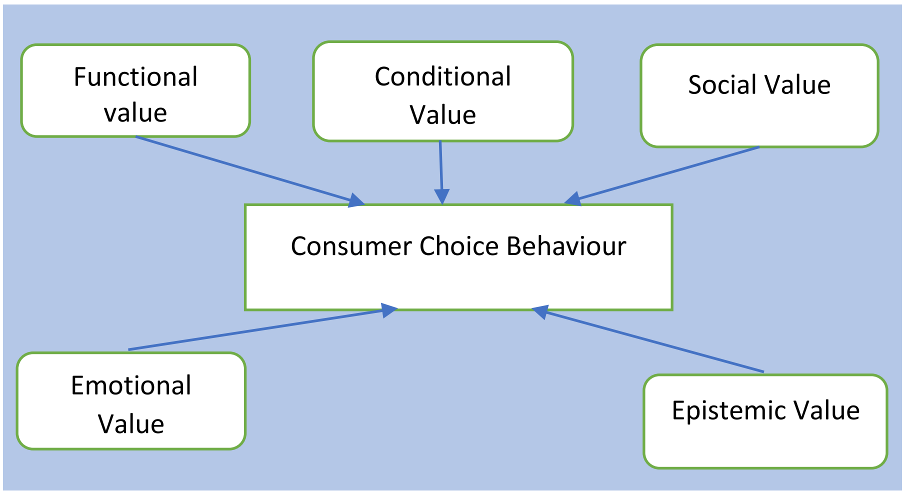

Figure 2.2: Five Values of Consumer Choice. Source (Sheth et al., 1991)

Sheth *et al.* (1991), describes the values as follows:

i) The *functional* value of an alternative is the perceived utility acquired from the alternative's capacity for functional, utilitarian, or physical performance. Functional values are presumed to be the primary driver of consumer choice.

ii) The *social* value of an alternative is the perceived utility from its association with one or more specific social groups through association with positively or negatively stereotyped groups.

iii) The *emotional* value of an alternative is the perceived utility acquired from its capacity to arouse feelings or affective states. This value is measured on a profile of feelings associated with the alternative.

iv) The *epistemic* value is the perceived utility acquired from an alternative's capacity to arouse curiosity, provide novelty, and/or satisfy a desire for knowledge. This stimulates consumers to look for alternative solutions.

v) The *conditional* value of an alternative is the perceived utility acquired by the alternative as the result of the specific situation or set of circumstances facing the choice maker. This value is measured on a profile of choice contingencies.

The researchers observe that a consumer decision may be influenced by any or all of the five consumption values. In addition, Amstutz (1967) and Howard & Sheth (1968) submit that consumers' decisions can be influenced by other factors such as the perceived need, current supply, awareness, attitudes and the importance of their environment.

2.2 Models of Travellers' Behaviour in Travel mode Choice

The models and theories reviewed in Section 2.1 had been used in several studies including modelling travellers' mode choice. Two particular studies of interest in travel mode choice are the Lovelock (1975) and Sheth (1976) models. The two works gave detailed processes of travellers' behaviours in travel mode choice using different methods.

Lovelock (1975) work was inspired by the Amstutz's microanalytical models. It conceptualises the travellers' mode choice decision as a flowchart model. The flowchart model shows the various steps involved in traveller's mode selection process to identify the alternatives available and specifies the interactive nature of the model's structure. The ordered steps also affirm (Howard & Sheth, 1968) assumptions that the travel mode selection process is systematic. The flowchart model suggests that individual traveller is an entity trying to satisfy certain travel needs by first evaluating the alternative travel modes. Subsequently, matches the perceived characteristics of available alternative modes against an "ideal" solution, and finally, select the travel mode which provides the best match (if it exists). While the model recognises the impact of psychological variables such as *personal emotion*, the roles of individual *attitude* and *perception* as well as the *need for information* from the environment and *past experiences* in modelling individuals, it neglects the influence of peer interactions on their behaviour. Such models according to Hassan *et al.* (2008) usually do not recognise the roles of uncertainties that could arise from social interactions in their decision processes.

Sheth (1976) presented a mathematical model that involves a psychological aspect of travellers' travel mode choice behaviour. The model shows that psychological factors can be explored to bring about changes in the desired direction. It also explains that travellers' expectations in their chosen travel mode are presumed to be in five-dimensional subjective space of mode utility that is based on the theory of individual choice behaviour. The five dimensions are the functional, aesthetic-emotional, social-organisational, situational and curiosity of the mode. These dimensions were later modified by Sheth *et al*. (1991) as discussed above. Each available travel mode is, therefore, evaluated with respect to these dimensions based on the travellers' *needs, wants, hopes, problems or barriers.* Sheth (1976) work recognises that each trip is presumed to have a somewhat different set of *needs, requirements, desires and problems* associated with it. Hence, the author concludes that the same travel mode might be best suited for one purpose but quite inferior to another. Sheth's idea on the variation in the dimensions and individual evaluation of alternatives is a useful concept that suggests the possibilities of having different stereotype groups within the population of travellers. Furthermore, it introduced the concept of uncertainty that is common in human decision processes.

The above studies provide backgrounds to the fundamentals of travellers' travel mode selection process. They also provide insights into the nature of the environment and requirements that support such a decision process. Hence, the studies are clues towards effective provisions of necessary supports for stakeholders in modelling and conceptualising modal shift problems in travellers' mode choice.

2.3 The Nature of Travellers' Mode Choice Systems

From the background of the theories and models reviewed in Section 2.1, several issues regarding the processes and the factors to consider in travellers' mode choice have been reviewed. The processes and the factors have common underlying components, which varied and treated differently in the studies. Such components include the system's environment within which the decision is made; the information-seeking strategy of the travellers involved in the decision-making process (either deep cognitive processing or not); the personal attributes of the decision-maker; the inclusion of social engagement among travellers as well as the attributes of the travel modes involved. Based on the underlying features, the following areas are identified as important to modelling travellers' travel mode choice process and as such divided into four categories: Environment, Personality, Social and uncertainties for further review.

(a) Environment:

1 *Systematic Decision Process*: Travellers decision process within a transport environment is systematic and depends on the travellers' situations.

2 *Stimulus from the System Environment*: There is the presence of stimulus from the system's environment that shapes the travellers' behaviours through the causal structure which seeks to explain "why" various decisions are made.

3 *Travellers' Novelty and Exploration*: There is a tendency for travellers' exploration within the transport environment. The exploratory, novelty seeking and variety-seeking motives usually activate the search for other travel modes, trial and switching behaviour (Howard & Sheth, 1968)

4 *Influence of New Information*: The travellers' frame of reference change with time as new information is received and assimilated within the transport environment. This explains that the same individual will not make the same decision at different points in time, and different level of cognition is required to make a decision.

(b) Personality

5 *Travellers' Attributes:* Travellers have attributes which include their traits, the needs and the expectations from the available travel modes. These attributes play roles in decision-making.

6 *Travel modes' Attributes:* The attributes of the travel modes determine the functional values that encourage or discourage travellers to choose them.

7 *Travellers' Attitude:* Travellers' decisions are determined by some form of attitude constructs that are derived from the individual perceptions of the benefits to be derived from the usage of a travel mode.

8 *Travellers' Heterogeneity:* There are enormous individual differences among travellers' preferences across the cross-section of the population as well as differences in traits including affective states, aspiration, tolerance to uncertainty etc.

9 *The objectivity of Travel Mode Evaluation*: Alternative evaluation of travel mode is subjective to the traveller and not in the objective reality of the travel mode's characteristics.

10 *Groups within Population:* The likelihood of having segments of the travellers who have a similar perceptual mapping of the travel modes within each segment but a contrasting mapping between segments explains the importance of conformists and anti-conformists' concepts in decision-making.

(c) *Social*

11 Social value drives individual travellers' choice, and the travel modes' attributes which are thought to be functional are frequently selected based on their social value.

12 Travellers' behaviour is influenced by group membership (e.g., conformity and anti-conformity).

13 Interpersonal Communication and Information Dissemination.

(d) Other features

14 Decision-making processes involve cognitive and time resources

15 The frequency with which the choice has to be made may require that different decisions will not always be made each time, or that the traveller will always think very hard about the decision to make each time (Lovelock, 1975).

16 Travellers make a decision under uncertainties that may arise from personal or social situations within the environment.

Furthermore, travellers' activities within a transport system constitute complex adaptive phenomena with emergent properties that exhibit nonlinear and dynamic behaviours. Karwowski (2012) therefore, observes that human-centred design of such emergent human-system interactions requires application of the theories of nonlinear, dynamics and complex adaptive system. However, the success of understanding such systems requires knowledge, design principles and methodologies of HF, PSY with those of the science of complex adaptive systems as well as modern systems engineering.

The premise of the human factors discipline is the systematic use of the knowledge concerning relevant human characteristics to achieve compatibility in the design of interactive systems of people, machine, environments, and devices of all kinds to ensure specific goals (Hollnagel, 2014). Many of the systems under consideration by HF studies including transport system exhibits complex behaviours. The behaviours which are often dynamic, emerging out of the complexity of the large number of either relatively simple and often fuzzy rules that drive the system or interdependent interactions between system components (Karwowski, 2012). Therefore, the following sections survey the concepts of sociotechnical and complex adaptive nature of the transport domain.

2.4 A Sociotechnical System's Perspective of Human Decision-making

The term sociotechnical system (STS) was originally defined by Emery and Trist in the 1960s to describe systems that involve complex interactions between humans, machines and environmental aspects of the work system. STSs are both complex and dynamic with their constituent parts being autonomous and yet interdependent (Appelbaum, 1997). The interdependent parts mutually interact in the system as a purposeful whole (Whitworth, 2011). This explains the system theory position that the STS's components should always be view as one rather than reduce a system to its parts. For example, to describe or analyse a traffic jam situation in the transport system, it will be more natural and sensible to have the holistic examination of the traffic situation that include all the vehicles rather than an individual vehicle that is involved. It will be difficult, if not impossible to understand what constitutes the behaviour of an isolated entity due to the influence of the system's factor and interactions in such a complex situation.

One critical insight shared by all sociotechnical theories, according to Hettinger *et al.*, (2015) is envisioning the ways in which modelling and simulation can potentially support the design and analysis of real-world systems. it is therefore beneficial to conceptualise travel mode choice process from the perspective of the transport system in which travellers operate. This will present opportunities for unforeseen interactions that may contribute to undesired and potentially risky outcomes if components are modelled independently. The STSs' emergent properties and the associated phenomena can have multiple causes and effects (many of which are unforeseen and unintended) that are highly context-dependent, and difficult to predict (Hettinger *et al.*, 2015). Hence, the use of traditional reductionist approaches to investigate such a complex system will generally only account for a small amount of the variance in factors impacting the performance of such systems *(Waterson et al.*, 2015). A reductionist approach believes that a system can be explained by breaking it down into its constituent parts. In a highly complex system, the majority of components' interactions may not be readily apparent upon even detailed examination of the system. Hence, employing STSs' design view in modelling travel model decision process will contribute to the understanding of the constraints imposed on the travellers by the system. It will also reveal how the constraints can be addressed to facilitate and stimulate their behaviours.

The sociotechnical framework has been used in many domains to help drive improvements in the system's performance and safety. Among the domains currently exploring the use of a sociotechnical are: medical system design (Carayon *et al*., 2011; Berg, 1999; Patel *et al.*, 2015; Berg *et al*., 2003), transport system design (e.g. Fischer & Sullivan, 2002; Stanton *et al*., 2013; Salmon *et al*., 2012; Larsson *et al*., 2010; Wilson *et al.*, 2007), education (Kim, 2008; Smith, 2007; Richey *et al*., 2014), and military (Jenkins *et al.*, 2008; Walker *et al.*, 2009). Furthermore, Carayon *et al.*, (2015) shared the views of social scientists who had approached the study of economic, political and other social systems from the related perspective of complexity theory in which sociotechnical systems are among. The general class of phenomena are referred to as complex adaptive systems, due to its inherent complexity, non-deterministic and emergent nature. The concept of complex adaptive systems is discussed in the following section.

2.5 Complex Adaptive System

Complex adaptive systems (CAS) (Holland, 2006) represent important contemporary problems that involve many components, including agents that adapt or learn as they interact with each other and their environments. Agents are entities within a system that have behaviours, learn from their experience, interact with other entities and the environment, and influence each other (Gilbert and Troitzsch, 2005; Macal and North, 2007). The complexity of the system arises from the diversity of adaptive agents distributed within the system. CAS can therefore, be difficult to model and to understand with the use of mathematical tools and reductionist approaches (Oughton *et al.,* 2018).

Holland (1992a) lists CAS's main properties to include *evolution*, *aggregate behaviour*, and *anticipation*. Evolution is the algorithmic process that produces agents' adaptive behaviours within a system. It therefore makes emergent behaviour of CASs intricate and difficult to understand. The aggregate behaviour experience in the CASs is as a result of the emergent behaviours from the interactions among large numbers of agents. Holland (1992a) observes that CASs form and use internal models to anticipate the future, establishing the current actions on expected outcomes. CAS agents learn from their experiences and adapt their behaviours so that they are better suited to their environment(s) (North *et al.*, 2013). Modelling these agents individually (with their attributes and set of rules that guide their operations) assists in observing the full effects of their diversity in attributes and behaviours. The mechanism for modelling the dynamics of CASs is provided by Agent-based modelling (ABM) (Bonabeau, 2002). ABM as a computational method has been used successfully to model CASs in many disciplines, including biology, ecology, supply chain, consumer market analysis, anthropology, military planning etc. (e.g. Abel, 1998; Lansing, 2003; Weisbuch, 1999). The ABM is discussed in Section 2.7.

2.6 Survey of Modelling Techniques

Simulation is a well-suited way of modelling and understanding a system. Robinson (2014) describes simulation from the perspective of a dynamic system as an imitation of a system as it progresses through time. The various types of simulation methods available include discrete event simulation, Monte Carlo simulation, system dynamics and agent-based simulation (Robinson, 2014). Discrete-event simulation is used for modelling the queening system, where a system is represented as entities flowing from one activity to another. Monte Carlos simulation models risk in an environment where the outcome is subject to chances. System dynamics is a continuous simulation approach that represents the world as a set of stocks and flows (Robinson, 2014). Agent-based simulation (ABS) is a stochastic method to model a set of autonomous agents that interact with each other in a certain environment (Figueredo *et al*., 2015).

In simulation models, one of the critical factors to consider is the level of details or abstractions to be included in a model (Vasudevan & Deikar, 2011). The importance of taking a level of abstraction is to determine what set of model information is relevant to a model goal, and what amount of information is to be included in the model (Law & Kelton, 1991); this must be done at the early stage of the model development life cycle (Sakano & Benjamin, 2011). In general, the amount of information required increases with the lowering levels of abstraction. Thus a 'low-level abstraction' model contains more information than a 'high-level abstraction' model. Moreover, different modelling and simulation methods are suited to different levels of details. For instance, the basic system dynamics simulation is good in simulating a model with the *roll-up or aggregate* level abstraction (Vinet & Zhedanov, 2011). An aggregate level abstraction generates a set of 'higher level' modelling concepts that contain a smaller quantity of information and often manifest themselves as a summary of the information contained at the lower level of abstraction. ABS is well-suited to simulate models at both aggregate and disaggregate levels. A dis-aggregate level modelling contains more information about the model and capable of investigating different model concepts such as goal, performance metrics, activities and objects.

Among the simulation methods, Gilbert and Troitzsch (2005) admit that ABS is a more appropriate paradigm to capture micro-level analysis of individual agents in a social system due to its capability to model a set of autonomous agents that interact with each other. A detailed overview of the agent-based modelling and simulation is reviewed in the next section.

2.7 Agent-Based Modelling and Simulation

Agent-based modelling and simulation (ABM/S) is a way to model the dynamics of complex systems and complex adaptive systems, and it has become an established approach for studying human-environmental systems (Sun *et al*., 2016; Beanland *et al.,* 2017). These submissions can be attributed to various ABS features including learning ability which allows agents to act in an unknown environment and develop new strategies by experience collection (Lorscheid, 2014). Agents are also capable of changing behaviours during the simulation in an adaptive way as they learn, encounter novel situations or as populations adjust their composition to include a larger proportion of agents who have successfully adapted (Macal, 2016). The basic idea behind the ABS is that the systems are built in a bottom-up perspective (i.e. modelling individual with global observation) which requires specifying the rules of behaviour of individual agents as well as the rules of their interactions. The individual modelling of agents allows for the full effects of their diversity with respect to their attributes and behaviours to be observed (Macal & North, 2010). Klugl & Bazzan (2012) and Elsenbroich & Verhagen (2016) explain further that the simulated agents will produce a phenomenon that can be analysed, reproduced, or predicted. This generative, bottom-up nature of modelling and simulation provides great potential for dealing with problems that the conventional methods such as mathematical and analytical modelling have difficulties capturing the core features of the original system.

Bonabeau (2002) summarises the benefits of ABS to include *flexibility* in incorporating the heterogeneous agents' attributes and apply the rule of interactions. Unlike other modelling techniques, ABS has the ability to capture *emergent behaviour* from the interactions of individual entities. In addition, it provides a *natural description of a system* that makes the modelling process closer to reality by allowing simultaneous modelling of system attributes (macro elements) as well as the heterogeneous individuals (microelements) as they occur in a natural system. However, to mimic the behaviour of humans they represent, agents require an adequate set of rules extracted from theories, observations and real-life data representing the population being modelled. By using ABS as a tool, stakeholders can take the advantage of the detailed description of agents at an individual level to better understand the macro-level behaviour of the social system.

2.8 Agent-Based Social Simulation

Complexity is the nature of social systems. Due to the heterogeneous nature of the social system's agents, Social scientists coined a new area of knowledge known as social simulation

(Gilbert, 2005; Jager; 2000), an area that focuses on the interaction between humans and their environment. Social simulation provides a suitable tool to both explore the dynamics of social systems as well as to test management strategies. The individual differences across the cross-section of the population can only be properly understood by a detailed micro-level psychological analysis of the phenomenon (Sheth, 1976). One of the themes of social simulation research according to Siebers *et al.*, (2009) is that even when agents are programmed with simple rules; the behaviour of the agents considered together can turn out to be extremely complex. However, the system complexity can be better understood when the ABM paradigm is employed. That is, the macro-level phenomena of the entire system can be derived by studying the consequences of the behaviour of micro-level agents (Lorscheid, 2014; Janssen 2012). This is a step to hypothesis generation and the formulation of suitable policies for interventions that can better shape the future of the social system investigated. Combining social simulation and ABM has been observed to be an appropriate technique for simulating social phenomena (Gilbert & Troitzsch, 2005). This research explores the opportunities provided by this new area of knowledge (i.e. agent-based social simulation) to examine the micro-level analysis feature of individual travellers as well as to gain insights into their social behaviours.

2.9 Agent-Oriented Model Development Frameworks

Building agent-based models require a thorough consideration of the elements of the model. The exercise could be a challenging task due to many factors including the level of abstraction necessary to achieve the model's objectives; and the heterogeneity of the agents across a population that needs to be adequately captured and incorporated into the modelling process. In addition, it is important to establish the means to identify patterns of system behaviour as they emerge from the agents' interactions (Siebers & Klügl, 2017; Macal & North, 2010). Several agents' modelling and development frameworks have been developed to serve as general analysis, design, and implementation methodologies for modelling social systems. Each of the methodologies focuses on different principles and purposes. The currently available frameworks are considered from the perspective of the requirements for holistic system views, capability for modelling individual entity including their context and support collaborative works that this research is aimed at. Therefore, the following relevant components are considered:

1) Modelling agents' contexts in the system's environment.
2) Support for collaboration provided.
4) Reusability.
5) level of abstraction considered, and
6) Support for Object and Agent orientations in the modelling process.

Consequently, the modelling methods and frameworks considered are those that focus on agent-oriented requirement engineering and have agents as conceptual modelling construct (i.e. basic modelling unit). Hence, the considered frameworks and methodologies have direct relevance to the aim of this research from the viewpoints of Agent-Oriented Software Engineering (AOSE).

2.9.1 The Agent-Oriented Software Engineering

Agent-oriented Software Engineering (AOSE) is a field that emerges as a result of mutual demand for interaction between agent and multi-agent computing, and software engineering (Weiß, 2001). Agent-based computing usually explores the system behaviour as a function of local interactions among low numbers of highly complex agents. Multi-agent computing on the other hands considered a large number of simple agents seeking a solution to a problem. The software engineering technology aspect supports the creation of methodologies and tools involved in the development of complex, distributed, large, open, dynamic, unpredictable, heterogeneous, and highly interactive application environments. Among the several available AOSE frameworks, the classification in this work is limited to methods with backgrounds of agent and multi-agent technology as well as those that support object-oriented principles.

2.9.2 Generic Architecture for Information Availability Methodology

Generic Architecture for Information Availability (GAIA) originally developed by (Wooldridge *et al*., 2000), is a methodology for agent-oriented analysis and design that is intended to have general application to a wide range of multi-agent systems at macro and micro levels. GAIA methodology is the first complete methodology proposed to guide a multiagent system from analysis to design. GAIA has several limitations among which the *first* is its suitability for the analysis and design of the closed multiagent system. A closed multiagent system favours agents that are benevolent to each other and willing to cooperate. Unfortunately, in real-life social systems, agents' behaviours are open, that is, they can assume different social behaviours including conformity, anti-conformity and superiority depending on their context (Jager, 2000). An agent conforms when it agrees and cooperates with a group and anti-conforms when takes the other position. An agent can also show the superiority of its status for others in the same social network. The *second* limitation of GAIA is that the notations proposed to model and represent a multiagent system and its components appear not to be suitable to tackle the complexities of real-world systems. Besides, the notations are not inspired by accepted software engineering standards. The GAIA's failure to employ the use of standard notation limits its application in the development of a collaborative modelling platform (Cernuzzi *et al*., 2004). The *third* GAIA's limitation is the level of abstraction taken in the analysis and design of the system. In social system models, it is important to specify the organisational rules, structure, and pattern that the system should take, GAIA lacks such agents' organisational abstractions. As a result of the limitations, GAIA has seen a few extensions focussing on various aspects of its shortcomings. For instance, Zambonelli *et al*., (2001) extend GAIA based on the concept of coordination models known from the areas of standard coordination languages; and Cernuzzi *et al.*, (2004) address the characteristics of open multi-agent systems in complex open environments and improve notation techniques. However, the extensions also suffer other limitations which include the inability to model interactions among agents.

2.9.3 Societies in Open and Distributed Agent spaces

Societies in Open and Distributed Agent spaces (SODA) (Omicini, 2000) is a methodology for the analysis and design of Internet-based applications as multi-agent systems. It is developed with a goal to define a coherent conceptual framework and a comprehensive software engineering procedure which accounts for the analysis and design of individual agents (Omicini, 2001). However, SODA is not concerned with intra-agent issues (e.g. decision making within an autonomous agent) but with the inter-agent aspects such as engineering of societies and infrastructures for the multi-agent system. It employs the concept of coordination models in achieving the objectives of inter-agent modelling. Although SODA aimed at defining abstractions and procedures specifically tailored to the engineering of agent societies and environment, SODA is not a complete methodology, since it intentional does not address intra-agent issues (Omicini, 2001). In addition, SODA fails to provide a good collaborative platform for modellers due to the lack of standard language notations (Molesini *et al*., 2008). Considering collaboration as one of the objectives of this research, SODA will not provide good modelling support.

2.9.4 The Interaction-Oriented Design Agent Simulations

Interaction-oriented Design Agent simulations (IODA)(Kubera *et al*. 2008). IODA is founded on the basis that in the simulation design process, the influence of one agent on another is often implicitly expressed within action during the simulation. Therefore, IODA methodology makes each interaction a software element where the interactions constitute the core of the design and designed independently from the agents. The positive side of IODA concept is that agents can participate in a set of interactions that are not specifically developed for them, and the template for the interactions can be re-used in many simulations of the same application field (Kubera *et al*., 2011). However, the IODA could be suitable for multi-agent systems but do not provide the necessary support for modelling the psychological aspect of an agent's behaviour. Due to this reason and other limitations, IODA has not seen many applications; its few applications include the serious game (SG)(Mathieu *et al*., 2012).

2.9.5 The Prometheus Methodology

Prometheus (Padgham & Winikoff, 2002) is an agent-oriented software engineering methodology that consists of three phases: *system specification*, *architectural design* and *detailed design*. The *system specification* phase focuses on the analysis techniques and system requirement definition to capture the system goals and sub-goals. The goals are systematically captured from the intentional words in the initial system documents. Once the main goals are identified, the other goals and sub-goals can emerge by using refinement techniques (i.e., asking how and why). The *architectural design* phase identified agent types and use system specification artefacts to build the system architecture. The system overall structure is captured in a system overview diagram and the scenarios are developed into interaction protocols. The *detailed design* phase uses the system architecture artefacts and develops the agent's internal capabilities and processes as well as the events analysis and plans. The events in this case are the problem scenarios to be investigated. The process diagram is used as a stepping stone between interaction protocol and plans (Padgham *et al.,* 2008). The Prometheus methodology had found some applications mostly in the multi-agent system environment including Designing of institutional multi-agent system (Sierra *et al.*, 2007) and in Multi-agent system architecture-oriented design for security of cloud data storage (Talib *et al.*, 2011). The Prometheus Design Tool (PDT) complements the methodology with the provision of supports for consistency design and development of a system. Although, the methodology does borrow agent UML (AUML) activity diagram notation to present the process specification, but the PDT does not provide any support for the process diagram. Also, the Prometheus methodology detailed design phase that turned the analysis artefacts into the implementation platform is based on the concept of Belief-Desire-Intention (BDI). The BDI architecture is designed for a single rational agent which does not provide good reasoning architecture for agents in a dynamic environment. The two features of the methodology make it not a good candidate for modelling a modal shift problem in a dynamic transport system where traveller's decision is not solely dependent only on own belief but also depends largely on the interaction with others and with the environment.

Although GAIA, SODA, IODA and Prometheus methodology can be used to model agents in some agent-based simulation environment, they are typically developed to model agents in a multi-agent system. Consequently, the following are some selected methodologies developed with the intention to model agents in the agent-based social simulation system.

2.9.6 Engineering Agent-Based Social Simulations

Engineering Agent-based Social Simulation (Siebers & Klügl, 2017) is a structured approach developed to provide systematic supports for ABSS model's design and reproducibility using software engineering tools and techniques. EABSS described the steps involved in modelling a social system as well as the necessary tools that can be used. Unlike the GAIA and SODA, it uses software engineering UML notations to promote the formal standard exchange of ideas among stakeholder from different backgrounds. EABSS provides a good general approach to social simulation modelling process given the detailed procedures provided in the methodology. However, EABSS analysis and design abstractions do not include details of agents' decision process as well as social networks consideration among agents. In addition, it fails to include how the agents' social environment can be analysed with respect to their dynamic participation within the environment. These blind spots of EABSS make the development framework not immediately suitable to model modal shift in travel systems.

2.9.7 Modelling Agent Systems Based on Institutional Analysis

Modelling Agent System based on Institutional Analysis (MAIA) (Ghorbani *et al.*, 2013) is a meta-model agent-based social simulation framework that automatically translates high-level system descriptions to executable software. MAIA was developed on the understanding and assumption that sharing of resources and interactions in social systems take place under institutional structures. MAIA extends Ostrom's Institutional Analysis and Development framework (IAD)(Ostrom, 2005) by building on the principle that social rules or institutions are elicitable to express individual behaviour in an extremely complex system like a social system. Its main feature is to analyse the system in which *individuals* and *institutions* are the key components. An *institution* is a set of rules used by a set of actors to organise repetitive activities that produce outcomes affecting those actors and potentially affecting others (Ghorbani *et al.* (2013) citing (Ostrom 1991)). Based on the concept of IAD, MAIA has five structures that serve as place holders for related concepts: the *collective structure* of the actor and their attributes; the *constitutional structure* as the social context; physical aspect of the system; an *operational structure* that represents the dynamics of the system and the *evaluative structure* to validate the outcome of the system.

MAIA meta-model is a comprehensive and well-researched methodology that can facilitate collaborative model development and support policy analysis. The support for collaboration is limited due to the rigid structures of its components which might not be easily adapted by the stakeholders. In addition, the *constitutional structure's* institutional statements (i.e. rules, norms and shared strategies) usage in the framework fails to consider choice-making in a nonlinear and adaptive environment where agents can assume unanticipated behaviour due to changes in the environment. Most importantly, the MAIA meta-model agents' behaviour that defines the actions that the entities (i.e. agents, roles, and physical components) of the system can engage in the *operational environment* does not explicitly provide for modelling unanticipated, unpredicted and nonlinear behaviours that are common to agents in an adaptive system environment. Considering the limitations, MAIA would not be readily adapted in its current form.

2.9.8 Comparison of Approach

Table 2.1 compares the characteristics of the model development frameworks reviewed in this section.

Table 2.1: Development Frameworks for Agents Decision Modelling

Modelling area and support	Provisions for the modelling area	Source(s)					
		GAIA	SODA	IODA	EABSS	MAIA	PROMETHEUS
Environment: The system boundary within which the actors operate.	Considered for modelling.	✓	✓	✓	✓	✓	✓
	Analytic process specified.	-	-	-	-	-	-
Standardised Language: Common language of communication among stakeholders.	Formal Language support.	-	-	-	✓	-	✓
Collaborative Support		-	-	-	✓	✓	-
Agent Interaction.	Not specified.	-	-	-	-	-	-
	Inter-agent.	-	-	-	-	✓	
	Intra-agent.	-	-	-	✓	✓	✓
Abstraction Level: The system-level description.	Direct translation to Software.	-	-	-	-	✓	-
	High level.	✓	-	-	-	-	-

	Individuals level: agent.	-	✓	✓	✓	✓	✓
Object and agency modelling support.	Object-oriented.	-	-	-	✓	✓	-
	Agent-oriented.	✓	✓	✓	✓	✓	✓

The table gives an overview of the capability of each of the frameworks in modelling various aspects of agents’ decision process in modal shift problems. The tick (✓) in the table indicates that a framework provides support for the modelling area considered, while a (-) means that the area is not supported by the framework.

The general insights from the reviewed frameworks are that while some aspects of complex systems such as the environment, agent’s-oriented support and abstraction level in modelling have received attention, other areas including analysis of agent's environment, the use of formal standard language, reasoning architecture with agents’ interaction have received less attention.

In modelling agent’s environment, all the frameworks considered recognise that the system’s environment plays important roles in agents’ decisions. However, none of the frameworks specifies how the activities of a highly dynamic traveller can be analysed in a complex and adaptive transport system’s environment. The failure in this aspect could be a blind spot or that researchers have not realised the need for such a dynamic analysis. However, the shortcoming will impact on the adequacy of the frameworks to model traveller agents in a dynamic sociotechnical transport system environment. Besides, the use of formal language in the design specification, all reviewed frameworks except EABSS and Prometheus do not emphasise the use of a software engineering technique and formal notations that can provide support for standard communication in a collaborative environment. While the EABSS extensively adopted SE techniques and notations, the Prometheus methodology only borrowed the use of UML at the architectural design phase to represent the process specification. This is not adequate as there is no provision for structural representation of the travellers’ behaviours and activities. The general failure on the use of standard specification language to support modellers with a formal expression of individual ideas in most of the frameworks makes them not suitable choices for inter-disciplinary projects where collaboration is important.
At the agents' interaction and abstraction levels, while most of the frameworks support individual agents, GAIA focus on a high level of abstraction that might not be suitable for fine granularity problems’ modelling that require investigating how travellers’ traits influence their decisions. Also, MAIA is a toolkit-like framework that translates the modeller’s conceptual views of a problem to executable software. Such frameworks might not support the flexibility required to model the unanticipated behaviour of travellers; and non-provision of analytic techniques for the system environment. With the in-depth analysis of the existing frameworks, to our understanding, none of the reviewed agent-oriented methodologies has demonstrated enough evidence to support adequate modelling of travellers decision making in modal shift problem in a complex transport system.

2.10 Gaps in Knowledge

From the outcome of the comparison of model development frameworks presented in Section 2.9.8, it is evident that none of the existing methodologies currently offers sufficient capabilities and flexibility to effectively model modal shift in travellers' mode choice.

Specifically, none of the frameworks provides support for:

- The means to analyse the dynamics of the travellers as they traverse the transport system environment.
- Consideration for modelling travellers' emotional perception at various stage of their journey as they dynamically traverse the transport environment.

In addition, some frameworks/methodologies did not provide supports for:

- Standard language that could promote better communication among collaborators
- Decision-making mechanisms with various information-seeking strategy.
- Modelling uncertainties surrounding travellers' decision-making process.

However, in order to address the gaps highlighted above, an ideal development framework and methodology should provide supports for:

- A framework that provides means of analysing the dynamics of the travellers as they traverse the transport system environment. This will allow the examination of their unpredicted and unanticipated actions at different stages of their journey within the transport system.
- Modelling travellers' emotional perception in different situations as they dynamically traverse the transport environment. Travellers' contexts at various points in the system play roles in their decisions.
- A standard language that will promote better communication among collaborators
- Modelling social interactions among travellers and the environment.
- Decision-making mechanisms with various cognitive processing that recognise the time frame and interactions in decision-making.
- Modelling the travellers' memory and uncertainties surrounding travellers decision-making process. This will assist in providing a better representation of their behaviours that mimics their real-life 'intelligent behaviour'.

To address all identified shortcomings, the identified gaps have been classified into three main areas as the focus for the requirements for the proposed framework/methodology:

i) Techniques to model the system environment with respect to travellers' contexts (temporal and spatial) and capture their perceptions at various points within the transport system.

ii) Techniques to measure travellers' emotional perceptions regarding their context as they traverse the transport system environment.

iii) Comprehensive reasoning architecture that incorporates social interactions (intra and inter-agents), extended cognitive processing, and accommodate uncertainty and time frame in travellers' decision processes.

Karwowski (2012) observes that the success of human-system integration efforts requires the fusion of paradigms, knowledge, design principles, and methodologies of HF with those of the science of complex adaptive systems as well as modern system engineering. Hence, from the above classification and the objectives of achieving a modal shift in travellers' mode choice behaviour, some potentially relevant tools and methods in HF, Social Science and PSY that could provide support for the development of the proposed framework and the methodology are reviewed in the following section.

2.11 Potentially Relevant Tools and Methods for the Proposed Methodology

The tools and methods review in this section include those from HF domain that support analysis of work design within a dynamic and emerging sociotechnical system; with those from the domain of PSY that supports capturing subjects' emotional state at various points as they traverse the system; as well as relevant reasoning and decision- making architectures that support effective modelling of adaptive agents.

Agent's decision is influenced by the changes in the environment among other things. The need to understand the impact of the environment on traveller's decisions, the following section reviews the techniques for analysing agents' in complex adaptive system environments.

2.11.1 Method for the Analysis of System's environment

"We cannot change the human condition, but we can change the conditions under which humans work."-James Reason

To adequately achieve the objective of modelling modal shift in a dynamic transport system environment, the understanding of the environment in which a traveller operates is important. Generally, when a situation needs improvement or when things go wrong in a system, it is noticeable in the users' reactions including their habits and attitudes. For instance, in travellers' travel mode usage, many people prefer private cars to public transport. The preference has been associated with the constraints in the alternative travel modes (Derek Halden Consultancy, 2003). Efforts to understand the causes or to improve users' experiences within a system are the concerns of HF. The premise of the HF discipline is the systematic use of the knowledge concerning relevant human characteristics to achieve compatibility in the design of interactive systems of people, machines, environments, and devices of all kinds to ensure specific goals (Hollnagel, 2014).

Humans frequently change and adapt in time to the environment. It is therefore going to be a good practice to pay attention to the constraints that shape travellers' behaviour within the transport system rather than the ways they use the travel modes. The idea would make it possible to support them in adapting their behaviour in a variety of situations, including unanticipated situations. Such an idea according to Stanton *et al*. (2013) would likely offer some solutions to improve their perceptions. Therefore, a framework with the analytical capability to conceptualise travellers' activities in various situations (temporal and spatial) within the environment is required.

Furthermore, the goals of gaining insights into the system's operation in HF can be accomplished through several analytic methods such as *activity analysis, incident/ accident analysis*, *task analysis*, and *work analysis* (Wickens *et al.* 2004; Naikar 2006; Bisantz and Roth 2007). Garrigou *et al.* (1995) describe *activity analysis* as "a methodology that aimed at understanding the operator's behaviour, operating strategies, thought processes and interactions with others in a given situation". Activity is always unique and object-oriented (Daniellou & Rabardel, 2007) because it is specific to a given context, and obtain one or more goals that might not be evident to the analysis at the outset. Due to its uniqueness of activity, the activity analysis is not suitable for unanticipated behaviours. In the incident analysis, a system is analysed to gain insight into the underlying causes of events (unanticipated situations) so as to prevent further incidents of a similar kind in the future. However, the traditional approach to human-centred design paradigm and work design efforts requires extensive knowledge of interactions between its components and overall system behaviour (Karwowski, 2012), not only the causes of incidents. Therefore, the *task analysis* method allows investigations into what an operator (or team of operators) is required to do, in terms of action and /or cognitive processes to achieve a system goal (Bisantz and Roth 2007; Vincente 1999). *Task analysis* can be used as the first step in system design that provides a minimum description of the observable aspects of actor's behaviour at various level of the details. However, the term *work analysis* is used to generally refers to work (operations) of the actor in the system which include unanticipated task demand (Bisantz and Roth, 2007). Therefore, work analysis is an approach in which task and activity can be analysed having in mind the work determinants in terms of economic constraints, workforce characteristics, technical process etc.

In the remaining part of this section, the discussion focuses more on the work analysis method because of its approach to system analysis that supports cognitive rather than physical and perceptual activities (Bisantz & Roth, 2007).

Techniques for Analysis

There are different approaches to task analysis in human factors which include normative task analysis, descriptive task analysis and formative task analysis.

i) Normative task analysis prescribes how a system should behave (Vicente, 1999; Elix and Naikar, 2008), hierarchical task analysis is one of the normative approaches.
ii) The descriptive task analysis such as Operator Action Trees focuses on analysing how a system behaves in practice (Naikar 2006; Bisantz and Roth 2007).

Jenkins *et al. (*2009) argue that the two approaches work by decomposing activities into a set of task sequences that can rarely be extended beyond stable and repeatable systems.

Contrary to system requirement that can be analysed with the normative and descriptive task analytic methods, the sociotechnical systems exhibit complex behaviours that are often dynamic, emerging out of the complexity of the large number of either relatively simple and often fuzzy rules that drive the system of interdependent interactions between system components. Hence, the two task analytical approaches will not be adequate to achieve the aim of this research. Consequently, an analytical technique that focuses on how work can be done so that inherent complex and adaptable situations can be handled will be appropriate. When seeking a model to gives a qualitative analysis of an adaptive system, Vicente (1999) suggest a formative approach.

iii) A formative approach recognises that many tasks are discretionary and hence, lead to unpredicted and unanticipated actions. That is, it can assist in generating new ways of doing work. The commonly used formative technique is Cognitive Work Analysis (CWA) (Rasmussen *et al.* 1994; Fidel & Pejtersen 2004), an HF approach to the analysis and support of cognitive work that gives insight into how environments affect actors' actions in a system. CWA identifies the constraints of the work environment on the actor, the purpose of the system, and the tasks the actor can accomplish within the constraints of the work environment (Fidel & Pejtersen, 2004).

The next section discusses CWA in detail, as a result of its formative analytical approach to systems' environments.

The Cognitive Work Analysis

Cognitive Work Analysis (CWA) is a work-centred conceptual model developed by Rasmussen and his group in 1994, to analyse cognitive work (Jenkins *et al.,* 2009). It is unique in its formative and constraint-based approach to modelling the possibilities for behaviour within complex systems. CWA aims to improve system design by identifying the constraints that must be respected across a range of situations for a system to perform effectively (Vicente 1999; Jenkins *et al.,* 2009). These constraints can accommodate a variety of work patterns (i.e. behaviour), including novel behaviours to deal with unanticipated situations that may arise in a CAS. This feature makes the CWA a formative approach to work analysis (Naikar *et al*., 2006). Many design applications such as health, education, interface design (Rasmussen & Vicente, 1989, Vicente, 1999); transport (Hoffmann *et al.,* 2017) military (Jenkins *et al.,* 2008) have seen the use of CWA.

The CWA applies five distinct layers in analysing a system each of which considers the system under analysis from different perspectives by modelling different constraint sets. The outline of the layers was first introduced by Rasmussen in 1994 Rasmussen *et al.*, (1994) and later restructured by Vicente (1999).

In this thesis, Vicente's structure of layers shown in Figure 2.3 will be used due to its wide recognition.

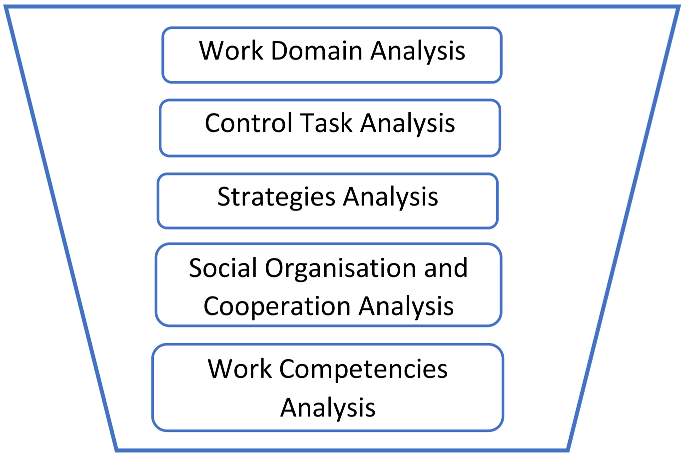

Figure 2.3: Five Layers of Cognitive Work Analysis. Source (Vicente,1999)

The five phases of analysis are: work domain analysis (WDA), control task analysis (ConTA), strategies analysis (SA), social organisational and cooperation analysis (SOCA), and worker competencies analysis (WCA). Naikar (2006) provides a detailed examination of the concepts of the five phases of CWA.

For clarity, the explanation of frequently used terms i.e. *task* and *work domain* according to what they represent in the traditional CWA is as follows. A task is what an actor does (i.e. the activities to be performed by the actor); a work domain is what actors do it on (i.e. the object of the action) (Vicente, 1999). For example, in a transport system environment, actors in the systems are the travellers, transport manager etc.; the tasks being performed by a traveller include making the journey with a travel mode, transport managers plan to ensure good services at all times. The work domain, in this case, is the transport system environments that consist of the people, transport infrastructures and other factors/components relevant to travellers' journey.

(a) Work Domain Analysis (WDA)

WDA is the most important part of CWA (Vicente, 1999), that considers the functions, purposes, and physical objects that constitute the system and the environment in which that system is situated (Naikar, 2006; Stanton *et al.*, 2013: Citing Rasmussen, 1974). It models the constraints that relate to system purposive and physical context in which workers operate. The main tool for modelling the purposive and physical work context or problem space of workers is the abstraction-decomposition space (ADS). Due to divergent theoretical approaches to WDA by the early researchers (e.g. Vicente (1999) and Rasmussen *et al.* (1994)) as to what should and not should contain representations of activity in the space. *Naikar et al.* (2005) developed a methodological approach which reconciled and earnest the earlier studies and easier to follow for non-experts.

According to Naikar *et al.* (2005), the ADS structures the problem space of workers along two orthogonal dimensions: the abstraction dimension and the decomposition dimension.
The abstraction dimension which is also referred to as the abstraction hierarchy or means-ends dimension structures the problem space of workers in terms of five levels: 1) purpose of the work system and the external constraints that affect its operation (functional Purpose); 2) the values and priority measures are the criteria which determine how the system progresses towards its functional purposes; 3) the general functions necessary for a system to achieve its functional purposes (purpose-related functions); 4) object-related processes are the functional capabilities and limitations of *objects* within a system which affect the functional purposes; and 5) the last level has the objects within a system referred to in the object-related processes. The top three levels of abstraction models the purposive properties of the problem space, define the reasons for the work system's behaviour, while the bottom two levels of abstraction models the physical properties of the problem space, define the resources for the work system's behaviour.

The decomposition dimension which also referred to as decomposition hierarchy represents the problem space of workers at different levels of details: whole system, subsystems and components. At the whole system level, problem space is described for the entire system as a single whole. At the next level, the problem space is described for each of the subsystems, and the third level described for each component. Naikar *et al.* (2005) explain that each level of decomposition represents a different level of resolution for viewing a work domain.

Table 2.2 shows the general structure of the ADS before coupling. The vertical dimension of the table represents the dimension of abstraction and the horizontal dimension showing varying levels of decomposition (system, unit, components) (Lintern, 2009).

Table 2.2: Generic Abstraction Decomposition Space. Source (Naikar et al., 2005)

	Whole System	Subsystems	Components
Functional Purposes			
Values and Priority Measures			
Purpose-related Functions			
Object-related Processes			
Physical Objects			

The two event-independent hierarchies (i.e. the *Abstraction Hierarchy* (AH), and the Decomposition Hierarchy (DH)) to investigate a system have been combined by Naikar et al. (2005) to form a two-dimensional space matrix called Abstraction Decomposition Space (ADS). However, the details of the fundamental principle behind the coupling of the two dimensions are not the interest of this thesis. In the literature, the ADS is generally referred to as Abstraction Hierarchy (AH), and the term will be adopted in this thesis.

Due to the adaptive and dynamic nature of human being in sociotechnical systems, the relationships between the different levels of abstraction in the AH are means-ends relations which are characterised in terms of how-what-why triads (Rasmussen *et al.,* 1994, Vicente, 1999). AH provides a psychological relevant way of defining the system by describing the relationships between functions at different levels of abstraction (Rasmussen & Pejtersen, 1990; Baker *et al.,* 2008), such that elements at one level of abstraction are the means to achieving elements at the next higher level, and the ends achieved by elements below.

Figure 2.4 shows the graphical illustration of an AH which is the primary tool to model WDA.

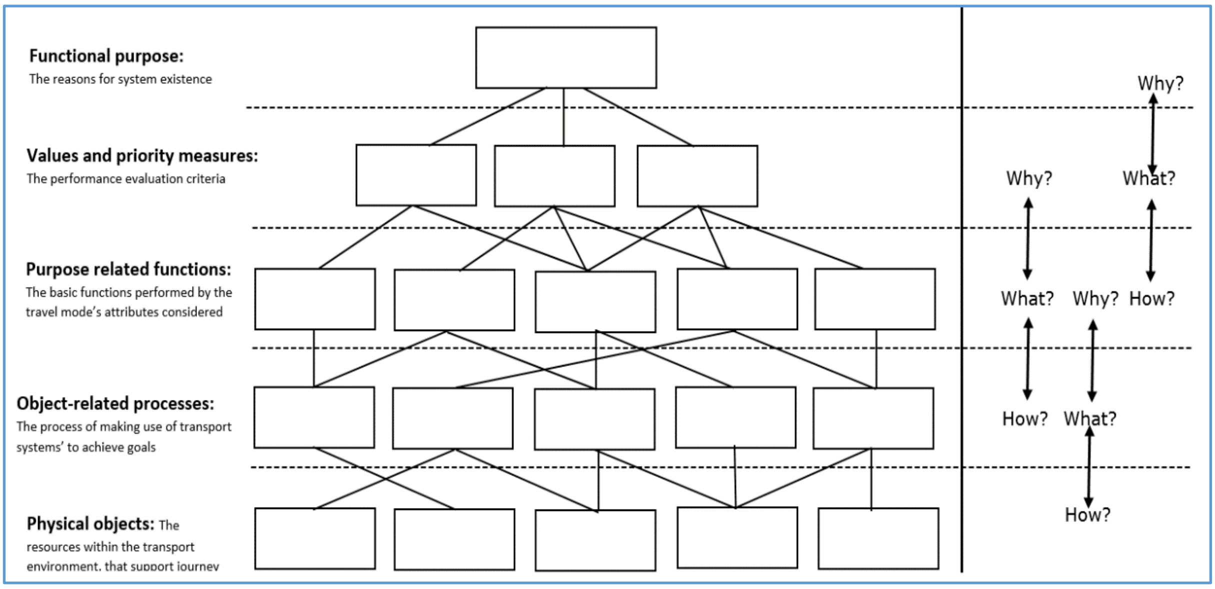

Figure 2.4: Explanatory figure of Abstraction Hierarchy. Source (Vicente, 1999)

The AH describes the system based on five levels of abstraction, each containing critical information regarding the work domain to be modelled: functional purpose, values and priority, purpose related functions, object-related processes and the physical objects.
The links are made following a *'how-what-why'* triad. It follows a process that when a node is taken as the *'what'* (at any level in the hierarchy), nodes linked in the hierarchical level above the node indicate *why* the chosen node is necessary within the system. Any connected nodes on the level immediately below that node can be taken to answer the question of *'how'* that function is to be achieved or fulfilled (Vicente, 1999). In other words, it examines the links between system functional purpose, values and priority, functions, process and objects from HF and actors' perspectives, and identifies the constraints on actors' behaviours that are imposed by the purposive and physical context, or problem space, in which actors operate (Jenkins *et al.* 2009).

(b) Control Task Analysis

Control Task Analysis (ConTA) is the second layer of CWA that complements WDA (first layer) by identifying the activity that is necessary to achieve the purposes, priorities and values and functions of a work domain with a given set of physical resources (Naikar *et al.*, 2006). Activity is the operations that an actor can perform in the system. ConTA aims to support workers in dealing with known, recurring classes of situations. In the original approach to ConTA (Rasmussen *et al.*, 1994; Vicente, 1999), the activities of an actor can be decomposed into sequences of tasks or actions (e.g. en-route the bus stop). The idea was consolidated by Naikar *et al.* (2006) to develop methodological guidelines for performing ConTA. In this thesis, the Naikar's terminologies and approach are reported, because it is more recent and commonly used in the latest literature.

Naikar *et al.* (2006) introduce the contextual activity template (CAT) to model ConTA.The CAT allows the activities first to be decomposed into a set of recurring work situations to deal with a set of work functions to perform. Activity is then further decomposed into the control task that is required for each work situation and/or work function. The approach makes it possible for the activity to be characterised as a combination of work situations and work functions. According to Stanton *et al.* (2013), modelling functions by situations allows CAT to be suitable in distinguishing between hard constraints (i.e those that require structural changes in the environment or technology to remove) and soft constraints (i.e. those that require changes in attitudes and behaviour to remove) in the system.

Furthermore, Naikar *et al.* (2006) explain that activity in some work systems is better characterised by both *work situations* and *work functions* of the actor. It is a *work situation* when activities are organised around time or location (Rasmussen *et al.*, 1994). For example, a traveller activity can be decomposed into a specific location such as 'at home', 'en-route the mode stop' etc. However, in some other work systems, activity may not be delimited in time and space, instead, activity may be better characterised by its content independently of its temporal or spatial characteristics (Rasmussen *et al.*, 1994). When the activity is organised in terms of its content, the classification into *work functions* will be appropriate Naikar *et al.* (2006), in other words decomposing the activity into a set of recurring work functions or problems to solve. In this case, the same traveller at the mode stop can be 'checking information on the display screen', or 'waiting for the bus'. For a car owner or cyclist, an activity can be decomposed to work function such as 'driving', 'riding' or 'looking for parking space'. Also, ConTA recognises, that the same goals may be accomplished in different ways depending on the situation; hence, it addresses the constraints on system activities imposed by a specific situation in which they are to be performed; but not concerned with how the activities are done or by whom.

Figure 2.5 shows a CAT that represents the activities in the work system that are characterised by both work situations and work functions. In the template shown in Figure 2.5, the work situations are shown along the horizontal axis, and the work functions are shown along the vertical axis. The circles indicate the work functions and the boxes around each circle indicate all of the work situations in which a work function *can* occur (as opposed to *must* occur). The bars within each box indicate those work situations in which a work function will *typically* occur. The template shows the context, defined by work situations, in which particular work functions can occur.

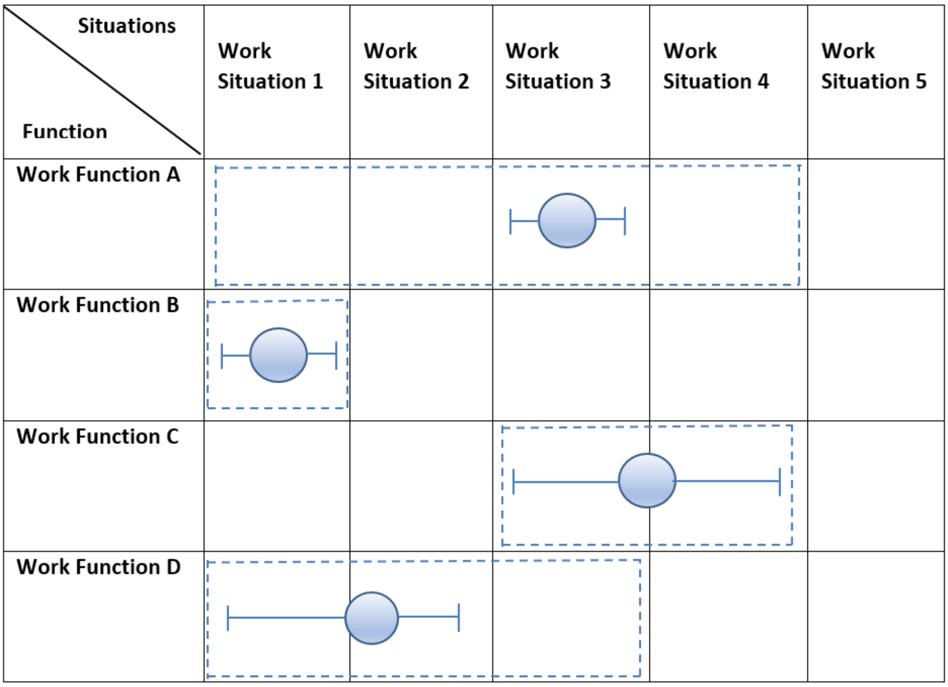

Figure 2.5: The Contextual Activity Template. Source (Naikar et al., 2006)

It also shows the various combinations of work situations and work functions that are possible. For example, in Work Situation 3, Work Function A can occur on its own, with Work Function C, with Work Function D or with both Work Function C and D. The work situations and work functions can be combined as shown in various ways to form the total response of actors. These various combinations will impose qualitatively different sets of cognitive demands on actors Naikar *et al.* (2006).

(c) Strategies Analysis

The third layer of CWA is the *Strategies Analysis (SA)* which models the mental activities used by the actors. Naikar (2006) explains that SA focuses on identifying the different ways in which activity can be accomplished by addressing the constraints that influence the way the activity can be conducted. ConTA (the second layer) is concerned with *what* activity is needed to be performed. SA describes several ways of completing the same task. The four key concepts of SA are:

1) The concerns for identifying general categories of cognitive procedures, which can be viewed as the abstract description of sequences of operations.
2) The recognition that several strategies are usually possible for performing a single activity. For instance, a traveller has several means of accessing information about its preferred mode (e.g. website, leaflets, information display screen, etc.).
3) The understanding that workers will often switch between multiple strategies while performing a single activity in order to deal with task demands. The switching at a given point in time will depend on the performance criteria of each strategy such as, the amount of time, memory load, and level of knowledge that is required for each strategy.
4) That it is important to identify the range of strategies that are possible as opposed to the range of strategies that are used by the actor. It happens that they may not use

certain strategies because of the demand (i.e. physical, cognitive, financial etc.), and as a result, they might not be using the most effective strategies.

However, by defining effective support for these strategies, workers will be able to adopt strategies that they otherwise might not use.

(d) Social Organisation and Cooperation Analysis

Social Organisation and Cooperation Analysis (SOCA) paid attention to actors of the system by looking at the constraints imposed by the social and organisational structures and specific actors' roles. It is aimed at identifying possibilities given the system boundaries, rather than current practices or standard procedure. It models how the activities are allocated among actors, i.e. among a group of individuals with distinct needs and requirements; what tasks and actions are performed by each actor, and how the task could be performed. The analysis at this stage can be influenced among other things by the actor competency, access to information, and workload required to achieve the goal. This stage gives the best results when modelled with a graphical display of information such as CAT (output from ConTA), and it could also involve all previous stages to generate the display.

(e) Worker Competencies Analysis

Worker Competencies Analysis (WCA) focuses on the tools and abilities needed by the actors to operate efficiently within the system. It addresses the constraints dictating the possible actors' behaviours in different situations. It is at this phase that actors evaluate their abilities based on the perception of the system environment.

However, traveller's experience within a dynamic transport system environment is associated with different feelings that reflect their context (spatial and temporal) as they traverse the system. The feelings or emotion is a key factor in peoples' decision making and traveller's mode choice is not different. Therefore, the following section investigated works in the psychology domain that focus on capturing people's emotional states.

2.11.2 Modelling Uncertainty in Decision Making

Human decision- making process in a CAS environment involve uncertainties. Computational intelligence (CI) techniques are required to handle such situations with the objective to understand and to mimic 'intelligent behaviour' among the agents. Engelbrecht (2007) describes CI as the study of adaptive mechanisms to enable or facilitate intelligent behaviour in complex and changing environments. Any methodology that is capable of assisting computers to behave intelligently in addressing complex world problems involving large, interdependent data, as well as imprecise and uncertain information is part of CI.

Very often, travellers considered many variables in their decision process to choose a preferred travel mode. The decisions which should be satisficing (i.e. good enough) are often made under uncertainty of imprecise, incomplete and dynamic information. Many uncertainty modelling techniques for modelling stochastic and dynamic decisions process are available in the literature. These include probabilistic systems such as Bayesian Networks;

Markov Decision Process (MDP) and its extension, Partially Observable MDPs (POMDPs) as well as the Fuzzy sets theory.

Bayesian Networks

Bayesian Network (BN) is a widely used method in modelling uncertain knowledge. BNs are a type of probabilistic graphical model that represents a set of variables and their conditional dependencies via a directed acyclic graph and Bayesian inference for probability computations (Kumar & Desai, 1996). BNs aim to model conditional dependence, and therefore causation, by representing conditional dependence as an edge in a directed graph, while keeping the computational complexity under control. With BN that deals with discrete variables, it is ideal for taking an event that occurs and predicts the likelihood that any one of several possible known causes was the contributing factors. For instance, a Bayesian network could represent the probabilistic relationship between a traveller's travel mode decision and the decision factors (e.g. physical, cognitive or affective considerations). That is, given the traveller final decision on travel mode, Bayesian networks can be used to compute the probabilities of the presence of any of the decision factors.

Formally, according to Sebastiani *et al.* (2005), if an edge (A, B) exists in the graph connecting random variables A and B, (e.g. traveller's decision and a decision factor) it means that $P(B|A)$ is a factor in the joint probabilistic distribution, so we must know $P(B|A)$ for all values of B and A in order to conduct inference. Hence, the joint distribution for a BN is equal to the product of $P(node|parent(node))$ for all node denoted as:

$$P(X_1, \dots, X_n) = \prod_{i=1}^{n} P(X_i|X_1, \dots, X_{i-1}) \; = \prod_{i=1}^{n} P(X_i|Parents\ (X_i))$$

The benefits of BN include the capability to model complex systems, to make predictions as well as diagnostics, to compute exactly the occurrence probability of an event and represent multimodal variables. BN has also found application in many disciplines including software reliability (Cai *et al.*, 2019), bioinformatics (Agrahari *et al.*, 2018), medicine (McLachlan, *et al.*, 2020) e.t.c. However, one of the current limitations of BN is that they can only deal with discrete variables (Weber et al. 2012).

Markov Decision Process and Partially Observable Markov Decision Process

Markov Decision Processes (MDPs) are the standard model for describing systems with probabilistic and non-deterministic or controlled behaviour (Korthikanti *et al*, 2010). Schaefer *et al.* (2006) argue that MDP is flexible to model classes of problems involving complex, stochastic and dynamic decisions. The essence of the model as stated by Littman (2015) is that at every state of an MDP, one or more actions are available, and each action is associated with a probability distribution over the successor states. For instance, in a traveller's decision-making processes, at a given time a probability may be assigned to each possible decision factor (i.e. physical, cognitive or affective consideration) to occur as part of the decision.

The system at any point can be represented by a probability distribution over possible states that the system may be in as formally represented below:

An MDP is a tuple $M = (S, A, T, R, \beta)$; where: S is a finite set of states of the environment; A is a finite set of actions; $T: S\ X\ A\ \rightarrow \Pi(S)$ is the static-transition function, giving for each state and agent action a probability distribution over states ($T(s, a, s')$ is the probability of ending in state s', given that the agent starts in state s and takes action a); $R: S\ X\ A\ \rightarrow \mathfrak{R}$ is the reward function, giving the expected immediate reward gained by the agent for taking each action in each state ($R(s, a)$ is the expected reward for taking action a in state s), and $0 < \beta < 1$ is a discount factor). Furthermore, a policy is a description of the behaviour of an agent. These policies specify, for each state, an action to be taken should the agent find itself in that state.

Some extensions of MDPs including *Markov game, partially observable MDPs* and *Semi-Markov decision processes* are quite useful. The Markov games models are closely related to the game theory where state transitions and rewards are controlled by multiple agents instead of a single agent. Agents select actions to maximize their personal total expected discounted reward.

The Partially Observable MDPs (POMDPs) have been developed to deal with imperfect information due to uncertainty in the decision environment with the objective to find an optimal policy based on the observations of the system and previous decision rules. Schaefer *et al.* (2006), submit that it is possible to replace the partially observed state with a sufficient statistic that can be interpreted as a likelihood estimation of the true state of the system given the observations seen; with this process, the model can be transformed to one with perfect information. However, Schaefer *et al.* (2006) further state that the downside is that the conversion will result in computationally intractable models for systems with even moderate-sized state spaces. In addition, a satisficing but not necessarily optimal policy is required for a traveller to make a travel mode decision.

The Semi-Markov decision processes allow decisions that occur over a continuous time interval to be modelled and allows the inclusion of a probability distribution over the amount of time spent in a state. For instance, the time between travellers' decision may depend on the action or may occur randomly. MDP and its extensions have found applications in many problems area involving complex, stochastic and dynamic decisions e.g. clinical medicine, epidemics, queueing. (White & White, 1989).

Fuzzy Sets Theory

When problems involve vague or ambiguous responses or whenever there is the possibility of uncertainty in perceptions, Zadeh (1996) suggests the Computing with Words (CW) methodology as a way of resolving it. The exploitation of the tolerance of imprecision is an issue of central importance in CW where words are used in place of numbers for computing and reasoning. Mendel (2001) observes at least three situations in which fuzziness should be considered: *intrinsic fuzziness* in the real-life system (e.g. description of similarity among travellers, or defining the degree of memberships of decision variables in a traveller mode choice), *multiple states* (depending on the environmental dictates), and *description of phenomena when our knowledge is incomplete or vague*. Both the intrinsic fuzziness in the real-life system and the description of incomplete knowledge are very relevant to the focus of this research.

Uncertainty due to fuzziness is inherent in any complex system, thus, in order to study complex artefact-human system, it is necessary to use modelling approaches that are approximate in nature. For example, to describe how a traveller perceived the urgency of getting to work or to determine the degree of contribution of decision factors (e.g. physical, cognitive and affective considerations) in a traveller decision. There are elements of imprecision and vagueness in both cases. Fuzzy systems and in particular fuzzy inference system are natural ways to model vague or ambiguous events that occur in human-like reasoning. The application of the fuzzy inference process on the fuzzy sets provides the needed modelling capacity. The concept of fuzzy sets is a powerful tool that provides a way that is similar to a human being's concept and thought process.

Bai & Wang (2006) explain that to implement fuzzy inference to solve an actual problem, three consecutive steps of fuzzification, fuzzy inference process and defuzzification must be followed:

a). Fuzzification, which is the conversion of the classical data or crisp data into fuzzy data of Membership Functions (MFs). In a classical set, an object can either belong to the set or not belong to the set. For instance, if X and Y are two different universes of discourse. If x belongs to X and y belongs to Y, the mapping between them can be expressed as:

$$\mu_A(x) = \begin{cases} 1, (x \in A) \\ 0, (x \notin A) \end{cases}$$

The concept of fuzzy sets is fundamentally broader set compared with the classical set that only considered a limited number of degrees of membership in a given range with a sharp boundary. The fuzzy sets allow members to have a smooth boundary, i.e. it allows a member to belong to a set to some partial degree. The partial can be mapped into a function or universe of membership values.

For instance, in a fuzzy set A, if an element x is a member, the mapping can be denoted as:

$$\mu_A(x) \in [0,1] \quad (A = (x, \mu_A(x)|x \in X)$$

That is, a fuzzy subset A with an element x has a membership function of $\mu_A(x)$. When the universe of discourse X is discrete and finite, this mapping can be expressed as:

$$A = \frac{\mu_A\,(x_1)}{x_1} + \frac{\mu_A\,(x_2)}{x_2} + \cdots + \frac{\mu_A\,(x_i)}{x_i} = \sum \frac{\mu_A\,(x_i)}{x_i}$$

When the universe X is continuous and finite, the fuzzy set A can be represented as

$$A = \int \frac{\mu_A\,(x)}{x}$$

Generally, fuzzification involves two processes: 1) derive the membership functions for the input and the output variables, and 2) represent them with linguistic variables. The process is equivalent to converting or mapping classical set to fuzzy set to varying degrees.

b). The fuzzy Inference Process combines membership functions with the control rules to derive the fuzzy output. The fuzzy control rule is the knowledge of an expert in any related field of application. The fuzzy rule is represented by a sequence of the form IF-THEN, leading to algorithms describing what action or output should be taken in terms of the currently observed information, which includes both input and feedback if a closed-loop control system is applied. However, the law to design or build a set of fuzzy rules is based on a human being's knowledge or experience, which is dependent on each different actual application.

c). The defuzzification process converts each associated fuzzy output back to the classical output to the control objective and formation of lookup table, as well as picking up the output from the lookup table based on the current input during an application. Since the control output is derived from the combination of input, output membership functions and fuzzy rules. The vague fuzzy elements, defuzzification process makes the fuzzy inference output available to real applications.

Analysis of Techniques for Modelling Uncertainty

An analysis of techniques for modelling uncertainty in this section indicates their varying capability to model different forms of human decisions under different conditions. BN is a very good modelling technique for a probabilistic relationship among variables that form a traveller's decision; due to its capability to model complex systems and their components as well as its ability to compute exactly the occurrence probability of an event. However, it is short of the capability to reveal the strengths or the degree of membership of each of the variables in the decision. Having the probability of occurrence of a variable (e.g. physical consideration) in a traveller's decision will not be enough information to determine the strength and knowing the degree of contributions of such variable to the decision. Since this is an aspect of interest of this research, the Bayesian networks would not be appropriate modelling techniques for uncertainties in traveller's mode choice process.

The MDP and POMDPs are good at modelling imperfect information due to uncertainty in the decision environment. With statistic, the partially observable MDPs can be transformed into one with perfect information and provide a likelihood estimate of the true state of the system given the observations seen. However, the MDPs are with the objective to find an optimal policy based on the observations of the system and previous decision rules. In traveller's mode choice process, appropriate decisions at a given time are not always the ones with optimum objectives but the ones with satisficing (i.e. good enough) situation. Therefore, knowledge about the likelihood of the system's state based on observations would not provide enough information on the contributions of the system components to the traveller's decision. Hence, the MDP and OPMDPs would not provide a good modelling technique for travel mode decision process modelling.

The fuzzy system and fuzzy sets, in particular, provides a good modelling technique for intrinsic fuzziness in the boundaries of the travellers' decision factors. Due to its capability to model phenomena when our knowledge is incomplete or vague, it provides a good modelling technique for the degree of membership of decision factors (input variables) and as well as an appropriate intelligent computational tool for accurate location of traveller's emotional states (points) when combined with an appropriate PSY model. Due to these features, the

Fuzzy sets provides immediate support for modelling imprecision, vague and fuzziness in travellers' mode choice decision process.

2.11.3 Modelling Human Emotional Perception

Emotions play a critical role in human reasoning and decision-making. Scientific evidence suggests that measuring emotional state is one of the daunting tasks in psychology and affective science (Mauss & Robinson, 2009). There are several schools of thought in PSY regarding what represents human emotion and there are also increasing consensus among these schools of thought that emotions are episodes of coordinated changes in several components (including neurophysiological activation, motor expression, and subjective feeling) in response to external or internal events of major significance to the organism (Scherer (2000).

There are several criteria to categorise the many current conceptualisations of emotion in the literature; these include the basic or fundamental emotions that centres on organisms' chances of survival (Richins, 1997), and the dimensional models. Although there is no agreed position among the psychology theorists of what qualifies to be basic emotions, they mostly shared the view that some emotions are basic and they form the basis for other complex emotions. The dimensional models of measuring emotion include the unidimensional and multidimensional models. Scherer (2000) argues that the proponent of unidimensional models while acknowledging the existence of a multitude of emotional states, are convinced that one dimension is sufficient to make the important analytical distinctions. The multidimensional theorist believed that the nature of the emotional state was determined by its position on the three independent dimensions: pleasantness-unpleasantness, rest-activation, and relaxation-attention. Scherer (2000) further note that Russell and Plutchik who had been the major writers that popularise the multidimensional models later postulated a two-dimensional scheme, with the standard emotions placed on a circle. The two- dimensional models graphically illustrate similarities and differences between emotions in terms of neighbourhood in space, and they have been at the basis of much recent physiological and neuropsychological emotion research.

The multidimensional models have also been the common techniques to assess customer emotional response to marketing stimuli. Among these is the pleasure-arousal-dominance (PAD) scale developed by Mehrabian and Russell in 1974. A further review of the psychology literature unearthed the Circumplex Model of Affect (CMA) (Russell, 1980). The CMA considered a multidimensional aspect of human emotions and stands in contrast to theories of basic emotions which posit that a discrete and independent neural system subserves every emotion. The Circumplex Model of Affect proposes that all affective states arise from cognitive interpretations of core neural sensations. The sensations are the product of two independent neurophysiological systems (Posner *et al.*, 2005), namely affective valence (also termed pleasure-displeasure) and perceived activation (also termed arousal) (Ekkekakis & Petruzzello, 2002), defined as orthogonal axes as shown in Figure 2.6.

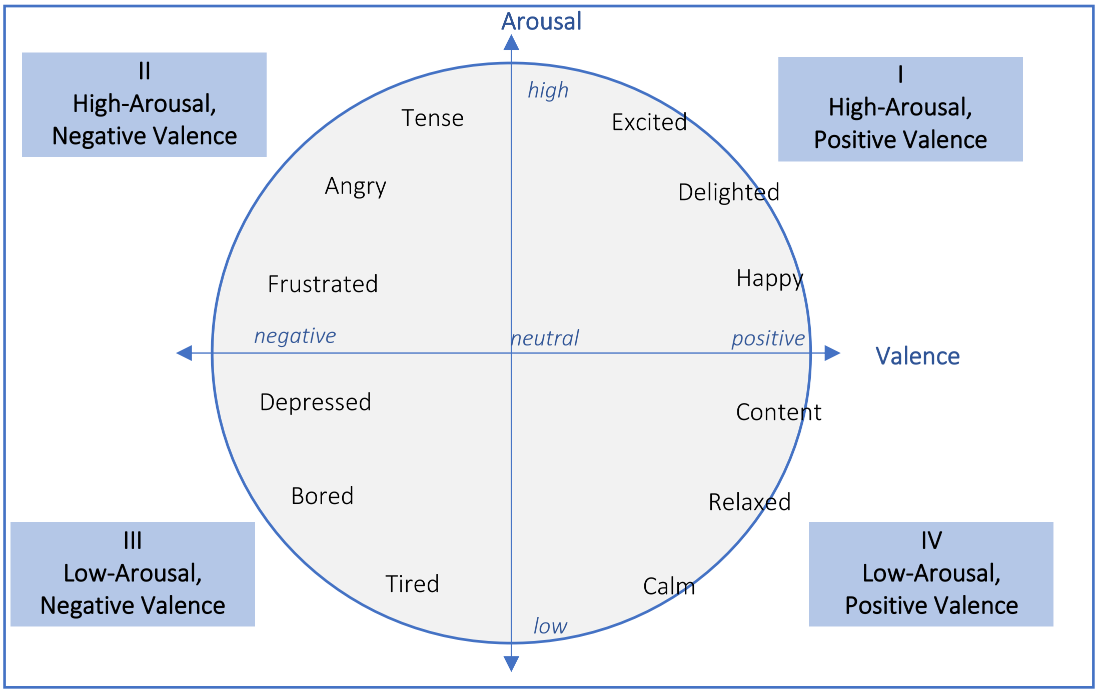

Figure 2.6: Circumplex Model of Affect: Source (Russell, 1980)

In the figure, plotted vertically is the arousal axis, which ranges from low arousal to high arousal. The valence axis, plotted horizontally, ranges from negative to positive. The two independent systems give rise to several different levels of emotion, which are represented in a circular fashion of a two-dimensional space of the model as shown in the figure. Posner *et al.* (2005) explain that when the two independent systems are observed they give rise to one emotional point. Some emotional points of the system will appear to be similar (e.g. *calm and relaxed* are two related feelings), but they are measurably different from each other. CMA has been described to be more consistent with many recent findings from behavioural, cognitive neuroscience, neuroimaging and developmental studies of affect. It has been successfully implemented in various areas including social behaviour (Carney & Colvin, 2010); medicine (Posner *et al.,* 2005; Tseng *et al.*, 2014) and e-commerce (Jascanu *et al.*, 2010).

Furthermore, in PSY, methods of obtaining human emotional state (affective display) had been through various means such as *facial expressions, bodily postures,* and *vocal expressions* (Sincero, 2012). Also, there are groups of techniques to collect data on human emotional state these include: 1) the observation of behaviours of the subject method, 2) the collection of measurement of body responses (e.g. heart rate) methods, and 3) the self-report method which measures feelings of emotions as reported by the subjects from their experiences (i.e. experienced emotion) rather than the actual current emotion. Among the various methods, the self-report method has been the most commonly used in consumer behaviour (Sorensen, 2008). Also, in a dynamic transport environment, the method will be appropriate as it allows travellers to recall and report their experiences.

Jager (2000) (citing Schachter, 1964) observes that the concept of emotion is associated with general arousal of the Sympathetic Nervous System. One of the sources of such arousal is the uncertainty that surrounds decision making, especially in a dynamic environment. As stated in Section 2.10, modelling uncertainty in the travellers' mode choice process is one of the focus of the proposed methodology. The following section examines human reasoning architecture that involves uncertainties.

2.11.4 Human Reasoning and Decision-Making Architectures

One of the challenges of modelling human reasoning is to construct a cognitive framework that is both realistic enough to capture an individual's reasoning process and simple enough to remain computationally efficient and comprehensible to the modeller (Balke & Gilbert, 2014). A substantial amount of works is available on human reasoning architecture in the literature. All are inspired by different aims and they all include one or more social theories. Such architectures range from basic ones that rely on single-theory such as Theory of Reasoned Action (Fishbein & Ajzen, 1975) and Theory of Planned Behaviour (Ajzen, 1991), to more complex and integrated meta-theories architectures such as ACT-R (Anderson, 1993) and SOAR (SoarTechnology, 2002).

Following the requirements identified in Section 2.3 (i.e. agent's environment, personality and social values) and re-defined in Section 2.10 as the techniques to model: (1) the dynamic system environment; (2) personal attributes that include emotional perception, cognitive processing, memory for learning, and uncertainty in the decision process; (3) social interactions involving inter-agents participations. The following relevant agent's reasoning architectures in artificial intelligence from well-established social and PSY theories are considered to address various human decision-making issues.

(a) Belief Desire and Intention

The *Belief Desire* and *Intention* (BDI) model is a human practical reasoning and decision-making model developed by Rao and Georgeff in 1991 (Georgeff *et al*.1998; Rao & Georgeff, 1995). An important feature of BDI is its mental state that is characterised by three components of *belief, desire* and *intention* as the basis for reasoning. *Beliefs* are the information that a human has about the circumstances and may be incomplete or incorrect due to the nature of human's perception. *Desires* are the states of affairs which a human would wish to be brought about, and *intentions* are desires which a human has committed to achieve. BDI is founded on a well-known theory of rational action that is based on a logical and simplified philosophical view of how people behave(Rao & Georgeff, 1997) but lacks sound psychological theories (Georgeff *et al.,* 1998); hence, there are criticisms from sociology and artificial intelligence (AI) researchers about the adequacy of the three concepts of its mental state. As a result, there are several extensions of the original BDI; these include the Emotional BDI (eBDI) (Pereira *et al.*,2005); Extended-BDI(Lee & Son, 2008); The Belief-Desires-Obligation-Intentions (BOID).

Balke & Gilbert (2014) observe that BOID and eBDI have the same restriction as the traditional BDI. Also, the cognitive level of the eBDI which allows for reflective agents does not provide any consideration for *learning* from past experiences, and *adaption* to a new situation. BOID allows modelling of social norms, the norms it supported are expressed solely in terms of obligation and its own goals. Generally, the present BDI models provide no architectural consideration to explicitly model multi-agents with *learning* and *social behaviour ability* (Lei *et al.*, 2012). BDI is particular about balancing between pro-active goal-seeking behaviour and reactive responses to the environment (Hickmott *et al.*, 2011; Simari & Parsons, 2011). This attribute is a useful feature for modelling agents with respect to changes in their environment. However, BDI as an intentional system emphasises less on the impact of external environment on the actor, and its reasoning architecture is designed for a single rational agent, thus entities' interactions, learning and expression of social ability in decision making are not supported. With our understanding of human reasoning and particularly about the choice-making decision process, the BDI model will be too simplistic to realistically capture the decision-making processes in travellers' mode choice models.

Balke & Gilbert (2014) citing Sun (2009) explain that the desirable features expected in a cognitively inspired model that will not limit the realism and applicability of social simulation should include cognition as an integral part of an agent architecture. Therefore, due to the inadequacy of the BDI architecture to model travellers' complex behaviour that is often dynamic and emerging out of the complexity of a large number of their relatively simple interdependent interactions, more comprehensive and integrated agent reasoning architectures are reviewed in the following section.

(b) The Cognitive Architectures

Cognitive architecture is inspired by different research disciplines including PSY, behavioural science, and cognitive science that are concerned with studying human cognition. Chong *et al.*, (2007) citing (Newell, 1990) describe an integrated cognitive architecture as a single system that consists of many modules (or components) working together to produce behaviour. The modules can contain representations of knowledge, memories for storage of content and processes utilising and acquiring knowledge. For the purpose of this research, a reasoning architecture that covers a wide range of human behaviours including purposeful behaviour, human cognition and adaptive behaviour in a dynamic environment would be appropriate. In this category are the ranges of simple cognitive architectures such as Physical, Emotional, Cognitive and Social (PECS) architecture (Schmidt, 2002); to more detailed ones such as the Consumat approach (Jager, 2000; Jager & Janssen, 2012); and to more strongly influenced neurology and psychology models such as CLARION (Sun, 2003) and ACT-R (Anderson, 1993).

I. The Physical, Emotional, Cognitive and Social Reference Model

The Physical, Emotional, Cognitive and Social (PECS) reference model (Schmidt, 2000) is a multi-purpose reference model for human behaviour in a social environment. It was developed to replace the BDI architecture due to its limitations. Urban & Schmidt (2001) explain that PECS is designed according to two designed principle: 1) *Component-oriented, hierarchical modelling* which makes it possible to functionally decompose complex models into a set of smaller model components. 2) *System theoretic approach* which concerns the description of attributes and model behaviour.

PECS is designed to be a general methodology suited for domain-independent modelling for human behaviour, considering the physical condition, emotional state, cognitive capabilities, and social status. The components of the model include the *environment*, *connector* and *agents*. The environment reflects the agents' knowledge, but PECS reference model provides little assistance in the aspect of how to analyse agents' dynamics as they traverse and interact within an environment. It also not specifies how agents obtain or seek information to assist their decision making within the environment. The connector is a component that serves as a central switchboard that organises the exchange of information between agents. While PECS provides an opportunity to manage agents' communication, managing multiple interacting agents' communication centrally will remove the autonomy of agents and defeat the purpose of the individuality concept in ABM. Besides, as demonstrated in the Learning Group model (Urban & Schmidt, 2001), the PECS's repertoire of possible actions in the agent's decision making is too simplistic, built around two needs of knowledge acquisition and social satisfaction. The architecture mainly provides theoretical concepts that cover issues on affective, social levels including the physical and cognitive aspect of the agent's decision-making process with limited applications found in the literature. This might be responsible for the limited actual implementations.

II. The Consumat Approach

The Consumat approach (Jager, 2000; Jager & Janssen, 2012) is an architecture that addresses the need for meta-theory in studying an aspect of human decision process by organising different social, psychological and economic theories in a unified conceptual framework for agent-based modelling. Originally developed for consumer behaviour in products choice. The Consumat approach explores both macro and micro driving factors that affect human behaviour. The *macro-level factors* are the *natural and human environment*s that consist of technology, economy, demography, cultures, institutions, within which individual traveller and other stakeholders operate. The resources within the environment are available and are applicable to all travellers within the system irrespective of status, thereby making the environment the decision context of actors. The *micro-level factors* often differ between persons; they are the basic driving forces of human behaviour which Jager (2000) listed as the *needs and values*; *behavioural opportunities*; *consumer abilities*; and *consumer uncertainty*.

(IIa) Consumat needs

Humans are characterised by their pursuit of satisfying various needs at the same time; therefore, in formalising the needs, the Consumat architecture relies on the popular Maslow's hierarchy of needs (Maslow, 1954) and Max-Neef (Max-Neef, 1992) to arrive at three main forces of *existence*, *social* and *personality* needs. The three needs also align with the three leading behavioural motives of Goal Frame Theory (Lindenberg & Steg, 2007).

The *existence need* relates to the means of existence, food, income, housing, transport etc., and hence basically dominated with the gain motive (Jager, 2000). In the case of a traveller, deciding which travel mode to use depends very much on the costs (e.g. financial, physical, cognitive, emotional etc.). A traveller would like to choose a travel mode that will cost less, and that provides a safe, efficient and comfortable transport means.

The *social need* relates to interacting with others, belonging to a group and having social status. This social engagement is believed to increase satisfaction when one performs the same behaviour as its peer. Jager (2000) and Jager & Janssen (2012) explain the two concepts that drive social need as *being similar* and *being superior.* For being similar, satisfaction increases when an agent performs the same behaviour as its peer. Identifying a peer to interact with is a key concept, and it can be linked to three aspects: 1) the agent's attributes such as preferences and relative importance of needs; 2) the state (i.e. the stock level of existence need), and 3) having the same behavioural opportunities (i.e. engaging in the same behaviour such as regular car users or co-public transport users). The similarity between interacting agents is formalised in the Consumat as the proportion of peers performing the same behaviour within a population; the more similar an agent is, the more interaction takes place (strong tie), the more a similar behaviour will result in the satisfaction of the social need. For being superior, the Consumat agent wants to be superior to its peers, this implies that an agent derives satisfaction from, e.g. driving a better car than its peers. This introduces weighting functions on the agent's social need, balancing the similarity and superiority drive.

The *personality need* relates to satisfying one's taste, engaging in activities one likes and being different from others (e.g., having a personal preference for a travel mode). Jager and Jassen explain that a behavioural option (e.g., car, public transport, cycle) may more or less fit with a traveller's personal preference (taste). The more behavioural option matches the taste of an agent the more satisfied the agent will be. The taste of an agent involves multiple ideal points (e.g., social, functional, emotional values) which affirms the theory of consumption values discussed in Section 2.1 (Figure 2.2). Agents prefer to minimise the difference between their ideal points and the corresponding scores of the available opportunities. However, due to multidimensional personality needs, in fine-grained modelling of preferences, both the weight of a taste and the position of an ideal point may vary. For instance, in travel mode choice, a traveller may find the safety of the travel mode very important and value a high score on that. Another traveller may also value safety but does not evaluate safety as important as the comfort of the mode.

Lastly on Consumat needs is the values which are described as the relatively stable beliefs about the desirability of behaviour, but in an unstable environment, a person's values are more likely to change. For example, unreliable public transport services (e.g., frequency or timeliness) will provoke a relatively unstable level of need satisfaction. In this example, the need for reliability is not satisfied, but when the overall profile of need satisfaction changes, also a person's cherished values will change.

(IIb) Consumat Behavioural Opportunities and Abilities

Behavioural opportunities are products and services. In the case of a transport system, these are the travel modes and their services that have the capacity to satisfy travellers' needs. There must be capacities to use particular behavioural options. The sets of capacities are referred to as ability. For a traveller, financial, physical, mental etc., are typical abilities that relate to the feasibility of making use of a travel mode. If a certain travel mode (behavioural opportunity) requires more abilities than the traveller has, the *behavioural control* is insufficient to make use of the travel mode, then dissatisfaction or uncertainty sets in.

Behavioural control is the balance between the resources the agent has and the resources that are demanded by the opportunity.

Consumat abilities are related to various personalities of the agent which include *personal traits*, *uncertainty tolerance, and ambitions*. The personal traits include but are not limited to cognitive, physical, and emotional capability. Some agents have more capacity to elaborate about the future outcome than others; this is reflected in their time preference focus. Personal abilities explain the importance of heterogeneity in human nature which plays a key role in social interaction with people of similar abilities.

(IIc) Consumat Uncertainty and Tolerance

Uncertainty regarding various elements of decision-making influences people's action. In Consumat, Jager (2000) submit that uncertainty can occur in the *existence need* and *social need*. For *the existence need*, there are uncertainties surrounding variability in the outcome of a decision. (e.g. variability in the expectation of travelling with a choosing mode). The first Consumat formalised this as the absolute difference between expected opportunity consumption (EC) and the actual consumption (AC) of opportunities as shown in the equation below:

$$U = ABS(EC_{O1..n} - AC_{O1..n})$$

Where the opportunities are the available behavioural options, for example, if the actual outcomes of making a journey with a chosen mode are close to the expectations, the uncertainty *(U)* of the traveller will be small. If the expectations and actual outcomes difference are large, the uncertainty of the traveller will be large.

The *social need uncertainty* is associated with the proportion of peers that perform the same behaviour such that the more other agents that are considered to be peers engage in different behaviour the more uncertainty will be experienced. However, the uncertainty is more or less the same for everyone; what makes the difference is how sensitive people are to uncertainty outcomes. The level of tolerance to uncertainty (i.e. the uncertainty tolerance, UT) is one of the factors that indicate heterogeneity in human nature. Jager & Janssen (2012) formalised the uncertainties in consumat as a weighted equation:

U (uncertainty) = β1 * (VARΣ t+1...t = n E) + β3.* (share peers behaving different).

Where β1 and β3 are the weights of both existence and social uncertainty, the ratio of (U/UT) determines the chances of using a more individual or social-oriented decision strategy.

(IId) Consumat Satisfaction and Ambition

The utilisation of behavioural options (i.e., opportunities) may satisfy or fail to satisfy consumer needs. Satisfaction implies the degree to which the needs of agents are satisfied by engaging in certain actions or using certain opportunities. If a need is satisfied, the motivation to use the relevant need-satisfying opportunity again will increase, for as long as the need remains satisfied. But when a need is not satisfied, the agent's motivation to use the opportunity again will decrease. The satisfaction of a need is based on the current utility derived from behaviour, and the expectations of the future utilities derived. For instance, if travelling to the university with public transport usually causes a student to miss the early hour lecture, the motivation to continue using public transport will decrease, especially when there are other means such as cycling.

Consumat has three satisfactions for each of the three aspects of needs: existence need, social need, and personal need. In the original Consumat the level of need satisfaction (LNS) defined as a number between 0 and 1 is given as a diminishing marginal utility function as shown in the expression below:

$$LNs_{it} = (1 - \exp{(-\alpha^* O_j)}$$

WhereLNs_{it} is the level of need satisfaction for need *i* at time *t*, with parameter α indicating the sensitivity of LNS_i for the consumption of opportunity $O_{j.}$

In Consumat II, the expectations of future utilities were added to reflect the representation of a rational agent. Depending on the area of application, type of need and decision, the future outcomes can be more or less discounted. For a traveller, for instance, it is not relevant to consider the type of travel mode that a peer might be using next year in estimating social satisfaction. However, a high school graduate who is interested in career selection may consider the future benefits of alternative careers and observe the behavioural option of a successful neighbour. In general, Janssen and Jager added a discounting formula into the need satisfaction as follows:

$$LNS(N_{x,o,t}) = \sum_{t=i}^{n} f(t) * U(N_{x,o,t})$$

In which $LNS(N_{x,o,t})$ is the level of need for need N_x , (i.e. one of the three) for using opportunity *O* at the current time step t. the discounting is realised through function $f(t)$, which is a decay function over time t_i^n considered. $U(N_{x,o,t})$ is the utility for need N_x provided the by opportunity *O* at time *t*. if $f(t)$ slowly declines steeply as it may be the case of travel mode choice, the agent will not be particularly interested in the future for determining its current level of need satisfaction.

However, when one of the three satisfaction levels decrease the agent will experience a motivation to improve the level of satisfaction in this area, which results in different decision strategies. The decision strategies depend on individual ambition level. While some agents will be satisfied with a low level of need satisfaction, other agents have high ambition and will want to increase satisfaction. Hence the ratio of individual aspiration to the need satisfaction (Aspiration level/ $LNS(N_{x,o,t})$ describes the motivation to increase satisfaction. Agents may have different aspirational levels for the three needs.

(IIe) Consumat Decision Making

The Consumat relies on the micro-level driving forces to formalise the individual and social-oriented decision strategies to provide different ways by which agents evaluate opportunities. The decision strategies range from a simple habitual to a more detailed heuristic of inquiring from others within the population.

After the Consumat agents evaluate their different needs, the agent's mental states can be satisfied or unsatisfied, and it can be certain or uncertain. Depending on their level of satisfaction and uncertainty, Consumat agents engage in decision making employing strategies that include focusing more or less on the behaviour of other people to find suitable behavioural opportunities. The key rules in this model are (1) the lower the satisfaction is, the more involved a consumat is to process the information on behavioural opportunities, and (2) the larger the uncertainty is, the more the behaviour of other people the consumat used to identify attractive behavioural opportunities. The key drivers of these rules are the ratio between ambition level/needs satisfaction and the ratio between uncertainty/uncertainty tolerance.

These updates consider that agents differ concerning the time-horizon they use in evaluating opportunities. Hence, the deepness of processing may differ considerably between agents, thus creating a continuum of decision strategies by restructuring the strategies as any of the following: 1) ***Repetition*** means the agent considers only the behaviour being performed now. 2) ***Optimising*** (extended deliberation), the agent considers all possible behavioural options available. 3) ***Imitation*** considers all behavioural options performed by peers (strong links), i.e. successful behaviours that are performed by a majority of others are most likely copied, also the behaviour of a successful peer that deviates from the group can be imitated. 4) ***Inquiring*** (extended social comparison), the agent considers all behaviour performed by all other agents (weak links).

With the different decision strategies that range from simple habitual to a more detailed heuristic of inquiring from others within the population, Consumat addresses the shortcomings in other architectures that see human actions as rational and calculative. The idea which denies the existence of habitual behaviour and emotional influence on human decision-making processes.

III. Adaptive Control of Thought-Rational

The Adaptive Control of Thought-Rational (ACT-R) cognitive architecture was originally developed by Anderson (1993). ACT-R’s main components are *a set of modules*, each devoted to processing a different kind of information, *buffers* and the *pattern matcher*. The modules are the perceptual-motor which takes care of the interface with the real world, and the memory modules consisting of the facts and productions. The buffers access ACT-R modules and serve as an interface with other modules, and the content of the buffers at a given moment represents the state of the ACT-R at that moment. The pattern matcher search for a production that matches the current state of the buffers. Only one such production can be executed in a given moment. When executed a production can modify the buffers and change the state of the system.

The ACT-R has strongly influenced neurology and PSY models. It embedded cognitive psychology with large mental structures for both short-term and long-term memories; and low-level functional processes that operate on these structures (Langley *et al.*, 2009). ACT-R has found applications in areas such as testing and explaining psychological phenomena, developing intelligent computer tutoring and creating agents for simulated training environment (Langley *et al.*, 2009). However, It puts limited emphasis on the agent's interactions with the environment and due to the complexity of their structures, modelling modal shift in transport system might not benefit much from such complicated frameworks. Moreover, applying computationally demanding frameworks such as ACT-R to thousands of agents can result in unmanageably high computational costs. For instance, to investigate the effects of several policies on the proportion of travellers that respond to interventions, one would not be interested in the fine-tuning of each agent's latency of information retrieval from the memory (Kangur, 2014), but rather the realism of response to the policy. As a result of the highlighted observations, ACT-R would not be a suitable architecture for the proposed framework and methodology.

Comparative Analysis of Human Reasoning and Decision-Making Architectures

Table 2.3 shows the capability of each architecture regarding modelling agents,

Table 2.3: Human Reasoning Architecture

Modelling Area	Behaviour/Components suggested being modelled	Source(s)		
		PECS	CONSUMAT	ACT-R
Environment.	Agents' curiosity/novelty- through information-seeking activities.	✓	✓	-
	Social systems (considering others in decision making).	✓	✓	-
	Agent needs.	-	✓	-
Social.	Range of social behaviour (conformist, anti-conformist, etc.).	-	✓	-
	Inter-agent interaction.	-	✓	-
	Intra-agent interaction.	-	✓	-
Personality.	Memory (own, others and behavioural opportunities features).	-	✓	✓
	Personal ability and traits (tolerance, ambitions, cognitive, emotions etc.,).	✓	✓	✓
	Attitude construct.	-	✓	-
Cognitive Process.	Range of cognitive processes.	-	✓	-
	Time discounting considerations.	-	✓	-
	Uncertainty.	-	✓	-
	Mental mapping.	-	✓	✓
	Knowledge acquisition.	✓	✓	✓
	Learning.	-	✓	✓
Agents Coordination.	Distributed.	-	✓	-
	Centralised.	✓	-	-

the environment and their attributes including agents' *social, personal,* as well as *information coordination* techniques that are particularly important to decision-making.

The modelling concepts considered are listed in column one of the table, while the specific aspects of the agent and the environment to be modelled are represented in column two. Column three presents the cognitive architectures considered.

The tick (✓) in the table indicates the aspect in which an architecture supports the concept under consideration; and the (-) shows the problem areas not supported.

From the table, it is indicated that PECS and Consumat approach recognise the environment in which the agents make decisions, while ACT-R put less emphasis on the agents' environments. It is also evident that all the reasoning architectures except the Consumat approach failed to address one or more areas of modelling agents' decisions process. For example, only PECS distinctly considered environments as a major component of the problem's area to be modelled but also failed to explain how a change in the environment can be captured. In the aspects of the social network, although, PECS identifies connections among agents but not explicit about how the resulting interactions can be modelled. ACT-R places less emphasis on social networking among agents, and individual personal attributes. Although modelling an agent's decision process is well covered by ACT-R, aspects such as uncertainty and ranges of specific cognitive processes common to agents in making selection decision are lacking. ACT-R like PECS and Consumat supports a range of modelling concepts considered, there is a limited understanding of how it can be used to model dynamic environment, social interactions and uncertainties in the decision process. However, the agents' coordination techniques in the architectures are distributed, which is suitable for autonomous agents, but PECS adopted a centralised coordination method. In the final analysis, Consumat presents a suitable option for the methodology's decision-making module.

2.11.5 Social Simulation Platforms

Software that are traditionally designed to model ABM can be categorised as:

1. General programming languages that are based on object-oriented programming such as Java, C++ and Python
2. Desktop application development such as MATLAB, and Microsoft Excel
3. Large-scale (scalable) agent development environments such as MASON, REPAST, Swarm and AnyLogic

In this section, the following large-scale agent development toolkits are reviewed on their capacity to model traveller's mode choice process.

NetLogo

The NetLogo (http://ccl.northwestern.edu/netlogo/) is a family of Logo platform with the primary purpose of providing a high-level platform that allows students down to the elementary level to build and learn simple ABMS (Railsback, Lytinen, & Jackson, 2006).

NetLogo is designed with a specific type of model in mind: mobile agents acting concurrently on a grid space with behaviour dominated by local interactions over a short time (Allan, 2010). It provides a simple yet powerful programming language, built-in graphical interfaces and comprehensive documentation. NetLogo includes its own programming language that is simpler to use than Java or Objective-C, an animation displays automatically linked to the program, and optional graphical controls and charts. The documentation and number of example models for NetLogo added to the ease of use of the platform. It also has a good user community that provides a lot of support for new users of the NetLogo. However, NetLogo lacks a true object-oriented feature which usually make it unclear which methods are associated with which agents. It is therefore difficult to extend even simple NetLogo models. NetLogo is limited in its capacity to be used as ABM development framework software.

AnyLogic

AnyLogic (http://www.xjtek.com) is a multi-modelling platform that incorporates Discrete Event, System Dynamics, and Agent-Based modelling paradigm. A Java-based platform with a range of functionality that can be applied in the development of agent-based modelling. AnyLogic comes with a library of examples of models that have developed for a diverse range of applications including transportation, health, computer and telecommunication networks etc. AnyLogic is a powerful platform for charting model output dynamically with advances in Statechart plugin facilities. These features would be suited to observe the dynamics in travellers' mode choice behaviours over time. However, the free students' version is limited in the numbers of agents that can be simulated at a time and the structure of its design as a toolkit allows limited additional coding. These features would not make AnyLogic a suitable platform for framework development.

SWARM

Swarm (http://www.swarm.org) was specifically designed for artificial life applications and studies of complexity at the Santa Fe Institute in 1994. It was the first reusable software tool for multi-agent simulation of complex adaptive systems (Allan, 2010). The objective of Swarm is to be a general language and toolbox for ABMs, intended for widespread use across scientific domains. The concept that the software must both implement a model and, separately provide a virtual laboratory for observing and conduction experiments on the model is key to Swarm. Another key concept according to Railsback et al. (2006) is designing a model as a hierarchy of "Swarms", a swarm is a group of objects and a schedule of actions that the objects execute. The Swarm design philosophy appears to have been to include software that implements Swarm's modelling concept along with general tools likely to be useful for many models, but not to include tools specific to any particular domain. It is more of a framework and library platforms. However, it has weak error handling and lacks garbage collection. It also has poor documentation and limited tutorial materials.

MASON

Multi-Agent Simulator Of Neighbourhoods/Networks (http://cs.gmu.edu/~eclab/projects/mason) (MASON) is a general-purpose ABM library, geared towards speed and large batch runs of the simulation. MASON is Java-based designed with a clear focus on computationally demanding models with many agents executed over many iterations. MASON design appears to have been driven largely by the objectives of maximising execution speed and assuring complete re-producibility across hardware. It is easily extendable for a wide range of multi-agent simulation tasks and included with a pre-existing library including JFreeChart graphing library and evolutionary computation package. MASON is a good choice for experienced programmers who are working on computationally intense models. Due to the objective of building models development methodology for a community of users from a different domain, the expertise to use MASON will be a setback for the accomplishment of this research aim. Also, when compared with other platforms such as Repast, MASON lacks some batch parameter file format support that Repast has and a little more difficult to set up GUI display and display agents in MASON than Repast (Railsback *et al.,* 2006). Although MASON provides good inspection of agents' states on screen, it is somehow difficult to draw icons (other than geometric vector shapes provided) for agents on screen. Nevertheless, MASON is an excellent choice for exploring adaptation (both evolution and learning) as well as network causality. It is a good modelling platform where speed and /or sophisticated batch runs are required.

REPAST

Recursive Porous Agent Simulation Toolkit (REPAST) (http://repast.sourceforge.net) is a well-established platform with many advanced features that started as a Java implementation of the Swarm toolkit (Berryman, 2008) but has diverged significantly from Swarm. The initial objective was to implement Swarm or equivalent functionality in Java, but Repast did not adopt all of Swarm's design philosophy and does not implement Swarms (Railsback et al., 2006). Repast was intended to support one domain- social science in particular and includes tools specific to that domain while MASON and Swarm are intended for any domain. Full use of Repast toolkit requires Java programming skills but the objective of making it easier for inexperienced users to build models has been approached in several ways by Repast project team. As a result, there are built-in simple models and the development of RepastPy and Reapst Symphony that is much easier to learn and to make model development.

The Repast simphony architectural design is based on central principles that are important to agent modelling including the support for OOP, agents' social networking, flexibility, and reusability of various components. Repast Simphony provides contexts and projections that allow flexible environments for agents to participate in different networks (Collier & North, 2013). Other notable features of Repast include its methods for reading input parameters, with specific features for batch runs, support for custom plain text file format and the XML file format using a custom schema. Repast also has modules for creating neural networks and Genetic Algorithm (GA) libraries which can be useful for implementing agent learning. The newer version including Repast Simphony can interface with statistical facilities such as R suite and WEKA for data analytics, although, the facilities are not part of it. It also has advancements in the inclusion of the statechart facility. However, Repast graphic display is low compare to AnyLogic.

Comparative Analysis of Social Simulation Platforms

An analysis of the platforms indicates that NetLogo is an easy-to-use platform with excellent documentation. It is useful to prototype models for a quick and thorough way to explore design decisions. However, its non-support for OO principles is a significant limitation of the NetLogo for modelling large models. It also has limited capability for reproducibility due to its inability to provide immediate access to the algorithms implementing its primitives.

MASON is a good choice for experienced programmers working on computationally intensive models, but it is particularly challenging for novices due to the lack of basic documentation. Also, setting up batch parameters and graphical user interface in MASON is difficult for non-experts when compared to other platforms such as Repast.

Swarm is more of framework and library platforms with a stable and relatively small and well organised complete set of tools with a clear conceptual basis. Its weak error handling and lack of garbage collection coupled with poor documentation and tutorial materials make Swarm not immediately the best platform for interdisciplinary modelling platform.

Repast is certainly the most complete Java platform among others (Allan, 2010; Railsback *et al.*, 2006), specifically designed with Social science in mind. In addition to implementing most of Swarm's functions, Repast added more useful tools including the multi-run experiment manager. Its execution speed is good compared to other platforms. Railsback et al. (2006) observe that Repast is a good choice for framework and library platforms due to its support for OO principles and a variety of versions that are easy to use for a novice. It also has a well-established community of users' interactions and documentation.

2.11.6 Software Engineering Principle

Since agent-based models are expressed through computer programs, building software that will be replicable, easy to maintain, and that support collaborations among experts should be important. The aspects of simulation models that contribute to their degree of replicability include representation formalism and development methodologies (Matteo *et al.,* 2006). Hence, Computer science practices including SE practices and principles (Booch *et al.*, 2007) that provide design pattern supports for modellers as well as formal specification languages are discussed in the following.

Software Engineering Concepts

Software engineering as an engineering discipline is concerned with all aspects of software development including the development of tools, methods, and theories that support software development (Sommerville, 2016). Since simulation is a software, its development process often follows the concepts and practices of software development. In general, there are two approaches to programming a simulation: programming from the scratch and using a simulation software package. Both approaches use an *object-oriented programming language* because object-orientation is the mainstream development paradigm. *Object-orientation* is about organising software around the concept of objects. An object is a basic unit of construction, that has some attributes, and can perform actions (operations or methods). Objects of the same type are grouped in a *class*. Object-oriented programming

(OOP) is an implementation method in which software is organised as a collection of objects, each of which is an instance of a class.

Simulation of large-scale systems such as sociotechnical systems requires a large number of different elements in system realisation due to its complexity. To program such as a complex system, one should analyse the requirements of the project, then develop a design from an object-oriented point of view that satisfies those requirements. This process is called *Object-oriented Analysis and Design* (OOAD). The fundamental idea of OOAD is to break a complex system into its various objects (Booch *et al.*, 2007). One of the most important design principles in software engineering is *separation of concerns*, which is the idea of separating computer software into sections such that each section addresses a separate concern and overlaps in functionality are reduced to a minimum.

OOAD processes in SE are better communicated with various graphical tools to promote understanding and consistency. The next section reviewed some useful tools for specification languages.

2.11.7 Language Specification Approaches

A specification language is a formal language used during system analysis, requirements analysis, and systems design to describe the *what*, not the *how* in a system. The roles of a formal language include the description of a set of modules that interact with one another in simple, well-defined ways, such that people could work independently on different modules, and yet the modules will fit together to accomplish the larger purpose (Guttag *et al.,* 1993). The model-based specification language is in many ways similar to that of programming where design notations and tools are used (Snook & Butler, 2001). This sub-section reviews some formal language specification including Prometheus Design Tool (PDT), Unified Modelling Language (UML) and the Overview, Design concepts and Details Document (ODD) Protocol.

Prometheus Design Tool

The Prometheus Design Tool (PDT) is a graphical editor which supports the design and development of intelligent multi-agent systems and complements the Prometheus methodology (Padgham *et al.,* 2008). The PDT allows the designer to enter and edit diagrams and descriptors for entities and check the design for various consistency conditions (Talib et al., 2011). Although, the PDT contains scenario description and protocol specifications and assists in maintaining consistency between the different levels and diagrams which will greatly reduce errors and inconsistencies in the design. It does not provide any support for the process diagram. Although, it borrowed agent UML (AUML) activity diagram notation to present the process specifications. PDT primarily take an implementation point of view and focus heavily on developing a system rapidly.

The Overview, Design concepts and Details Document Protocol

The Overview, Design concept and Details (ODD) document protocol first published in Grimm et al. (2006) to standardise the published descriptions of individual-based models (IBM) and agent-based model (ABM). It is a documentation standard that provides details of what expected to be included at every stage of the model development with the objectives to make the model description more understandable, complete and aid reproducible. Generally, ODD is founded on the principles that first an overview of a model's purpose, structure, and processes should be provided; before the principle and rationale underlying its design, i.e. 'Design concepts'; and then 'Details' needed to re-implement the model are provided. To use ODD in IBM and ABM descriptions, the seven elements in the three blocks of ODD are the guides to the developer to know what is required to be included at each stage of the model's development. The revised version of ODD (Grimm et al., 2010) improves the rigorous formulation of models and helps to make the theoretical foundations of large models more visible. ODD did not include the techniques or a particular method to use to achieve the model. It has been applied to describe IBM and ABM models including three explicit models of land-related social processes (Polhill *et al.,* 2008) and others. The conclusion is that ODD is good to describe agent-based models. In general, ODD is more of documentation guide to describe models to enable reproducible and ambiguous model interpretation and not a development framework in the class of the AOSE.

The Unified Modelling Language

The Unified Modelling Language (UML), developed in the 1990s by Gardy Booch, James Rumbaugh, and Ivar Jacobson (Deitel & Deitel, 2011) is an attempt to create formalism, independent from development methodology, that can be used to represent both the static application structure of software implementation and different aspects of its dynamic behaviour (Matteo et al., 2006). The principle of UML design is that computer programs cannot be represented with one formalism only, but also graphical diagrams are necessary to give a reader the key to understand, replicate and modify a program. UML is a widely accepted standard for visual representation in object-oriented software development and it is extensible and independent of any particular design process. It is a flexible standard language to visualise, specify, construct, and document the artefacts of software systems (Pardillo, 2010), as well as business modelling and other non-software systems. Among the several standard modelling diagrams supported by the UML are the class diagrams, use case diagrams, activity diagrams, state machine diagrams, and sequence diagrams. The use of UML graphical notations to describe the structure, interactions and processes among system components have several advantages within interdisciplinary context (Bersini 2012; Vermeir and Bersini 2015). These advantages include capturing the entire system structure, agents and their behaviours; providing design documentation that shows how system elements fit together, thereby keeping the design and implementation consistent, hiding and exposing details as appropriate, promoting unambiguous communication, representing static and dynamic parts of the problem under investigation, and allowing reusability and easy maintenance.

Suitability of the Language Specification Approaches

Considering the suitability of the three language specification tools reviewed in this section, it is clear that the PDT is useful for the design and development of intelligent multi-agent systems and support consistency in design, especially when used within the Prometheus methodology. However, its lack of notations to represent systems' structure and agents' behaviours (except for the process specification) limit the use of PDT as a suitable specification language for the proposed framework/methodology that this thesis discusses. The ODD is a good documentation guide to describe models in order to enable reproducibility and avoid ambiguous model interpretation, but its lack of facilities to support structured design makes ODD not a suitable specification language to support the development of the proposed framework/methodology that this research aimed at. Among the tools discussed in this section, the UML provides the needed standard for visual representation in object-oriented software development. It provides supports to create formalism independent of development software. The UML graphical notations provide interdisciplinary projects team with the flexibility to communicate software architecture properly and effectively with the documentation of systems' components structure, interactions, and processes. UML is a software-independent language that provides detailed information about the design architecture and documentation of artefacts of software systems, hence it will provide suitable standard language to document and describe the development of a framework/methodology that supports collaborations.

2.12 Summary

In this chapter, we have reviewed research works on the fundamental principles that guide travellers' behaviours in travel mode choice. From the survey of relevant literature, systems' features and factors that support, and influence travellers' decisions are identified. Existing agent-oriented software engineering development frameworks such as GAIA, SODA, IODA, PROMETHEUS, EABSS and MAIA are reviewed. Each of the frameworks has different limitations that make them unsuitable for modelling travellers' behaviours in an adaptive transport system environment. The identified gaps include the static views of the environment, lack of standard language for communication, limited supports for agents' interactions, complex or too simplistic agent's reasoning architecture and lack of modelling capability for traveller emotional state and uncertainty in system's environment. The gaps gave the direction of the areas to explore for relevant domains of knowledge where tools and ideas that can assist the achievement of the research aims can be sought.

To address the static views of the system's environment. Several of HF' analytical techniques including activity analysis, incident/accident analysis, task and work analysis were reviewed among which task and work are considered suitable after in-depth analysis. In the category of task analysis, the CWA is found suitable due to its formative approach to task analysis.

The uncertainty modelling techniques considered include Bayesian Networks, Markov Decision Process and Partially Observable Markov decision Process and the Fuzzy sets theory.

The CMA is considered suitable to provide modelling support for travellers' emotional perception.

The reasoning architectures considered include the BDI, Consumat approach, PECS and ACT-R. The strengths and weaknesses of each were investigated. With an in-depth analysis, the Consumat approach was found suitable for the purpose of modelling travellers' decision process.

Several social simulation platforms including Netlogo, MASON, Repast, Swarm and AnyLogic were considered for the simulation software. The analysis of the platforms showed that Repast Simphony provides a suitable IDE for the methodology's library development.

To address the limitation of communication standard found in the existing frameworks. Language specification tool that includes PDT, UML and ODD were considered. After the comparative analysis of their strength and weaknesses, the UML was found suitable in providing the needed support to achieve the aims of this research.

3 Research Design

This chapter presents the research design that includes the methodological approach for this research. Section 3.1 discusses the research strategy for the development of the framework and the methodology that addresses the identified gaps. An overview of the framework/methodology requirement is given in Section 3.2. Section 3.3 presents a figure of a high-level overview of the components of framework/methodology and how various techniques chosen in the methodology are connected to the tasks. The discussion about the chosen tools and methods and further justification for the selection is presented in Section 3.4. The summary of the justification for the methodological steps taken is discussed in Section 3.5.

3.1 Research Strategy

Taking the research gaps (Section 2.10) and the objectives to be accomplished in order to achieve the aim of this research into account, the following are the methodological approaches and strategies for the research. The objectives of the research stated in Section 1.2 give directions and the execution of the approach. They also provide the reasons for respective methods and tools chosen in the research.

Some research domains are sufficiently broad that they embrace a wide range of methodologies (Nunamaker *et al.,* 1990). The methodology to adopt can be informed by the objective of the study, the mode of enquiry used in conducting the study or the applications of the findings of the research study (Kumar, 2011). In this research, the methodology was derived from three perspectives. First, from the perspective of the *objectives of the research*, the research is going to be *descriptive*, *developmental and exploratory.* It is *descriptive* because objective 1 systematically describes the travellers' mode choice process within the transport sociotechnical system's environment so as to understand the problem domain. It is *developmental* as the research's objectives 1 and 2 lead to procedures that yield useful concepts for a better course of action. It is *exploratory,* the research process explores knowledge from other disciplines with techniques in Computer Science to develop a new methodology for social science study (e.g. investigating modal shift in transport system). Furthermore, from the perspective of the *enquiry method* to be used in the study, this research adopts both structured and unstructured approaches. It is structured in the format of knowledge gathering template and, unstructured in the aspect of objectives of the specific case studies to be investigated, the sample to be taken and actual questions for data collection. Lastly, from the *research application* perspective, the research is applied research because the outcomes of the research process will enhance the understanding of factors that influence people's decision in travel mode choice and also support policy formulation.

In order to be guided in this research by the principles of the methodologies highlighted in this section, the strategies employed are highlighted in Figure 3.1. The diagrammatic overview of the plans and procedures start from the literature survey process (first box), through to the case study testing of the methodology (sixth box) that this thesis presents.

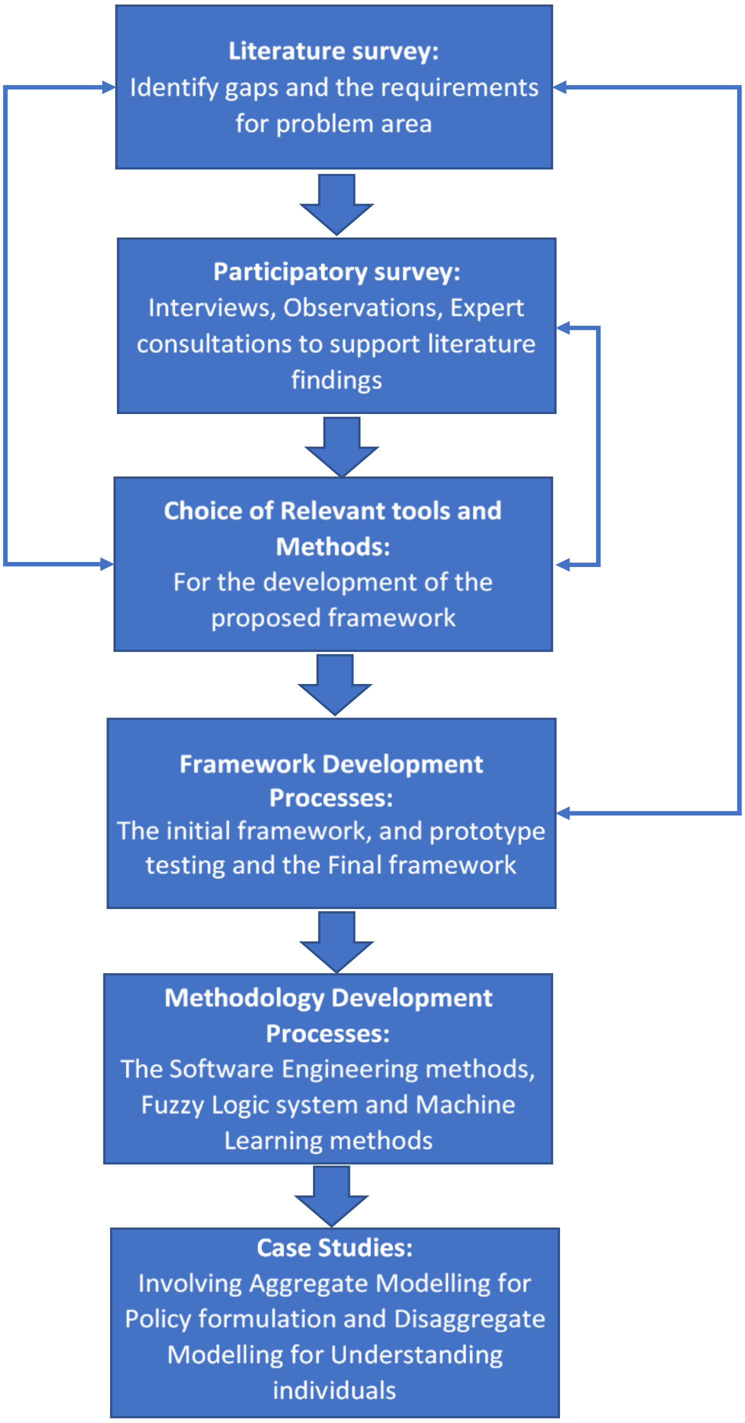

Figure 3.1: Outline of Research Strategy

The bidirectional arrows connecting the first three boxes with the fourth box in the figure indicate the iterative processes involved in seeking appropriate information to assist the choice of relevant tools and the development of the framework.

(a) Literature Review

Relevant literature survey on travellers' main considerations in decision-making, as well as the reviews of the existing models and model development frameworks that address traveller's decision making, are considered at this stage. The findings from the surveys coupled with the existing identified gaps (Section 2.10) provide information for the identification of necessary components to be included in the proposed framework.

(b) Participatory Surveys

In addition to information gathered from the literature survey, participatory survey (Chambers, 1994; Parrado *et al.,*2005) as a special investigative method to gain more information about people in social research was carried out. The purpose is to gain close and intimate familiarity with travellers' everyday practices and ways of dealing with the existential challenges in the transport environment. In addition, to give the research a real-life contextual view to validate the findings from the literature and to identify the gaps (if any) between the real-life scenarios and literature findings. For the survey, personal observations, interviews and consultation methods were employed.

The surveys help in identifying the domain of knowledge that offer relevant supports in achieving the aim of this research. The insights gained from the literature assisted in shaping the design to focus more on aspects of travellers' behaviours (e.g. waiting too long at a bus stop during bad weather, or running late for an appointment) that need further investigations. A range of additional scenarios regarding travellers under different situations is included. For example, opinions of nursing mothers were sought about their perceptions of travel modes in specific cases including situations when a mother with the buggy is unable to catch the available public transport due to the buggies' space already occupied by other users. In such situations, it may take some minutes before the next bus arrives. Other scenarios are cyclist held up by traffic light at the junction during bad weather (e.g. snow, rain); an office-bound pedestrian splashed (get wet) with running water after the rain by a not too careful driver, etc. Such selected cases further unveil other requirements such as the impact of emotional states on traveller's decision making.

(c) The Chosen Tools and Methods

The outcome of the participatory survey exercise coupled with the findings from the literature provided further direction for the choice of relevant techniques and tools that offer assistance in solving the identified gaps (Section 2.10). The tools are integrated into the development of the proposed framework as part of the methodology presented in this thesis.

(d) The Framework Development Process

For the first time, various relevant domain-specific tools and models are brought together to develop a novel framework that can assist in conceptualising traveller's mode choice scenarios in the transport system. The framework development process involves an initial framework design idea and the final design. The framework's element includes the CWA which is the task analytic tool and the *agent decision module* for the consumer's behaviour model.

The initial framework design presents the *environment* as a distinct entity of the system in which only the agent operates. This idea was used to model a prototype situation (a pilot trial) that focus on travel mode shift from road to rail. The intention is to evaluate the effectiveness of the framework. The outcome of the evaluation process revealed that there is limited clarity about the interactions that exist among the major actors in the system and the system's environment. The identified shortcomings necessitate the need for improvement so as to provide a framework that can be used in wider modal shift problems which resulted in the final framework design.

(e) Methodology Development Process

The methodology included the final design of the model development framework mentioned above. The methodology development process involves the use of SE methods and tools to define the structures of the framework's components. There are also procedures and processes to model various aspects of a problem including the use of Fuzzy system to model uncertainty in travellers' decision process and Fuzzy inference system that provide modelling solution to the expert knowledge used in travellers' affective measurement. In addition, Machine learning techniques are included to provide support for intelligent data modelling. There are various templates, processes, and procedures for establishing standard communication among a project team. The methodology includes a development process map to be followed by interested users in order to model a scenario.

(f) Case Studies

The case study approach is adopted in testing the effectiveness of the framework and the methodology in modelling problems at different levels of details. Apart from the pilot study, two different cases are investigated in the transport domain. The first used the framework alone to model a problem at a higher level of abstraction. The second employed the entire methodology and focuses on understanding individual entities within the system with a focus to investigate the impact of both ergonomics and psychological factors on travellers' travel mode decisions.

3.2 The Overview of Examples in Travellers' Modal Shift Problems

To bring to focus the different tools and techniques that are required in the development of the framework and the methodology, the overview of two case studies reported later in this thesis is presented. The first case study focuses on stimulating travellers' behaviours from motorised to non-motorised travel on short distance journeys. The study is to demonstrate the use of the framework/methodology to model problems at the aggregate level and for policy formulation support. The second study focuses on understanding individual travellers' responses to behaviour's driving factors. The driving factors are the variables that constitute a traveller's decision. The purpose of the case study is to demonstrate the use of the methodology to understand what constitutes individual traveller's decisions among the main travel requirements (i.e. the physical, the cognitive, and the affective considerations), and what level of considerations of these requirements are involved in individuals' decision to satisfy their needs.

3.2.1 Stimulating Modal Shift from Motorised to Non-Motorised Travel

The framework is used to model public views within the city of Nottingham regarding challenges associated with short distance journey (e.g. getting to the grocery store or walking distance workplace) with travel modes that demand physical efforts. The specific aim is to investigate how both ergonomic and psychological factors within the non-motorised travel environment (e.g., walking, cycling, etc.) impact on the travellers' decisions to travel with the modes that require more physical abilities on their short distance journeys.

Generally, the idea is that travellers make journeys by always first evaluate their needs and the purpose of the journey. For instance, on a short distance journey such as walking to a grocery store for shopping; there may be a need for a luggage carrier. The traveller then evaluates available non-motorised travel modes with respect to the needs; if a suitable non-motorised travel mode is found, it is adopted, else, the travellers' usual motorised travel mode (e.g., motorbike or a car) is used. The policymaker module of the framework is activated when there are perceived changes (e.g., unpleasant situation such as traffic jam) in the transport environment as a result of the travellers' mode usage behaviours. The policymaker investigates the travellers' concerns regarding non-motorised travel and develops strategies to alleviate the concerns. The policy interventions and the influence of social interactions among the travellers (motorised and non-motorised users) on their mode choice behaviours are observed, the insight from the experimentation provides the basis for recommendations for repositioning of the non-motorised transport system environment.

3.2.2 Understanding Individual Responses to Decision Factor

The second study extended the use of the framework into a methodology with the inclusion of processes and procedures that provide disaggregate level modelling to better understand the impact of individual travellers' attributes on their travel behaviours.

The travel experiences of a set of travellers to a University regarding their abilities to make use of alternative travel modes are examined in this case study. The purpose is to understand what constitute the decisions made by individual travellers among the main travel requirements that include physical, cognitive, and affective considerations. Also, what level of considerations of these requirements are involved in the travellers' decisions to satisfy their needs. Individuals abilities to use a travel mode is influenced by *ergonomics factors* including the constraints within the transport system's environment as well as *psychological factors* such as concerns for safety which impact on their physical, cognitive and emotional views.

The framework is first used to model traveller activities in evaluating the available travel modes within the University with respect to their needs and capabilities before a suitable travel mode is adopted. The policymaker module of the framework is activated when there are unpleasant effects (e.g., inadequate parking space within the University). Then the policymaker investigates the travellers' concerns regarding other less used travel modes, develop strategies and formulate policy to alleviate the concerns. The methodology includes the standard data collection process as well as the procedures to derive their affective display at the various situation during the journey. It also, the methodology ensures the procedure to achieve collaborative modelling among experts from different domains.

3.3 The Framework/Methodology Requirements

For the development of the framework/methodology, the following requirements are defined:

- analyse travellers' activities in a dynamic transport system environment.
- ensure realistic behaviours of travellers.
- model travellers' emotional state at various stages of their journey.
- apply OOAD principles for a structured transparent modelling approach.
- use open source software for the simulation.

A high-level overview of the connections between the framework's/methodology's components and the tasks of tackling the problems to close the identified gaps is shown in Figure 3.2 with more details in Chapter 4 and Chapter 5.

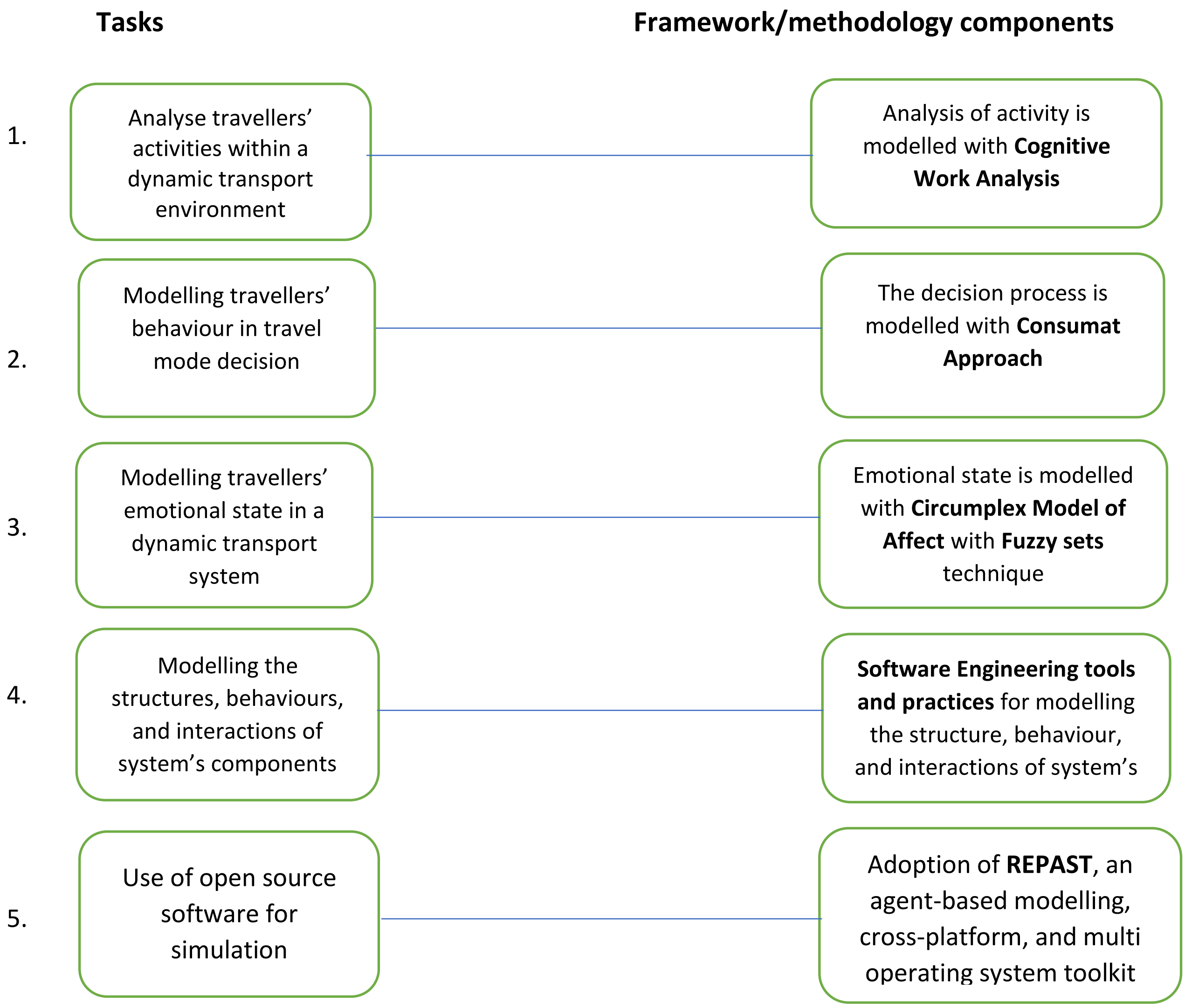

Figure 3.2: High-level Overview of Framework/Methodology Components

The framework components consist of the *Cognitive Work Analysis* for the analysis of the system's environment and the *Consumat approach* for modelling the travellers' decision process. The additional components that make up the methodology are the *Circumplex Model of Affect* to capture travellers' emotional state, as well as the processes and procedures for data collection and the structured modelling approach with Software Engineering principles.

The connections between each of the requirements and the components of the system are explained as follows:

- The first requirement of the methodology is to model the dynamics of individual travellers and attributes including their abilities to use a travel mode (e.g. the physical, cognitive, and affective considerations while making decisions).
- The second requirement in the methodology is the provision of modelling support for realistic travellers' behaviour.

As travellers traverse the system environment, they encounter different situations that influence changes in their emotional state and behaviours. The proposed methodology provides modelling support for a range of behaviours including the unanticipated traveller's behaviour. For instance, a traveller may not necessarily engage in deep cognitive processing each time it makes a travel decision depending on its mental state (i.e. satisfied or unsatisfied, and certain or uncertain). When satisfied, a traveller makes an automatic decision such as repeating previous mode choice behaviour. When unsatisfied, a traveller tends to engage in deep cognitive processing.

- The technique to derive a traveller's affective display from the survey data is the third requirement in the methodology.
- The fourth requirement in the methodology is the application of OOAD principles in the design and representation of a structured transparent modelling approach for the components of the methodology; the ease of adaptation of generic aspect to other cases and ease of collaboration among experts.
- The fifth requirement involves the use of open-source software as the development environment for the simulation.

To fulfil the framework/methodology requirements, tools from relevant domains that are included in the development process are presented in the following section.

3.4 Chosen Tools and Methods

The rationales for the use of relevant tools combined with SE techniques and intelligent data analytics methods are presented as follows:

3.4.1 Cognitive Work Analysis

To analyse the dynamism in travellers' activities within sociotechnical transport system, the CWA (Rasmussen *et al.* 1994; Vicente 1999) is chosen due to its formative analytic ability to understand how system constraints shape travellers' mode choice. CWA is used to analyse the system environment from the perspective of individuals that operate within the system. It also provides a holistic approach that makes it possible to analyse several dimensions of a context simultaneously and facilitates an in-depth examination of those dimensions. The CWA provides this research work with three key analytical benefits: 1) modelling traveller's unanticipated behaviour; 2) investigation into the constraints imposed on travellers' actions by the transport environment; and 3) provision of simultaneous analysis of the decision factors, the travellers, and the environment. Four phases (i.e., WDA, ConTA, SA, and SOCA details in Section 2.11.1) out of the five traditional CWA analytical phases are applicable to modelling problems related to travellers' modal shift and behaviour change. The last phase of the traditional CWA (i.e., Competence Analysis) which involves users training is not relevant to the aim of this research and hence, not included. However, the use of the four phases largely dependent on the modal shift problem being investigated. All the phases might not be applicable in all situations. The outputs of CWA provide information that supports design activities in a system.

3.4.2 Consumat Approach

To ensure a realistic behaviour of the agents in ABSS, it is important to equip them with the properties and behavioural patterns of the people they represent. The properties include the reasoning process, the needs, and abilities, as well as their activities and interactions with other agents within the environment. This applies to the representation of travellers in the transport system environments. In this research, the Consumat approach is incorporated into the methodology to provide modelling support for the travellers' mode choice process in the system. The supports are in four key areas*: cognitive, social interaction and networks, learning, and norm* consideration (Balke & Gilbert, 2014). In the cognitive aspect, the Consumat approach provides modelling solution for travellers' reactive, deliberative, simple cognitive and psychological behaviours. The social property of consumat allows travellers to distinguish between social needs and personal needs; as well as to compare own success to that of their peers. The learning property provides for modelling the travellers' memory (mental map) that stores information about their abilities, the opportunities (i.e. travel modes) available to them and the characteristics of other travellers. Norms and institutions as inputs into the model provides for the impact of different policies and interventions on the travellers' behaviours. The properties all together make Consumat a suitable choice to model the travellers' mode choice process in the methodology.

3.4.3 Circumplex Model of Affect

Travellers' emotions play a role in their decision. To incorporate the means of obtaining travellers' emotional state into the methodology, an established psychology modelling technique, the Circumplex Model of Affect (Russell, 1980) (CMA) is used with the Fuzzy sets system. The decision to use CMA among various techniques available in psychology is based on its considerations for the multidimensionality of human emotions. The Fuzzy sets system rather than Bayesian networks and Markov Decision process provides a better representation of the membership of points for the factors that contributed to the traveller's decision. It also provides better modelling support for the two independent dimensional space that constitutes the CMA (i.e., the Expert knowledge). The CMA supports the methodology to factor the effects of major decision variables into travellers' perception, as well as the overall decision. With CMA, the traveller's emotional perception would be obtained from the measure of how *satisfied* and how *important* they perceive the aspects of the travel mode or transport system being investigated. The two independent measures (i.e., *importance* and *satisfaction*) as input into the two-dimensional space of the model give rise to the point that represents a traveller's affective display as discussed in Sections 2.11.3.

3.4.4 Software Engineering and Object-Oriented Analysis and Design

The Software Engineering Object-Oriented Analysis and Design principle as part of the research strategy provides the methodology with the capacity to analyse, structurally design and represent the transport system's components. The research's aim of ease of knowledge communication and collaborative support among experts informed the adoption of SE practices and principles to provide conceptual standards for stakeholders to interact. The language specification as part of the strategy provides a formal standard way to describe the system's components to facilitate ease of communication among collaborators.

Object-Oriented Analysis and Design (OOAD)

This research employs the use of OOAD due to its support for modelling real-world scenarios that consist of agents and objects with behaviours, characteristics, and states. OOAD emphasises modularity and re-usability (Booch *et al.,* 2007), extensibility and the economy of time and cost (Sommerville, 2016). Reuse of a part of software results in a reduction of development and maintenance time and effort (Robinson *et al.*, 2004). The objects that can be reused include codes, components, architectural patterns, processes etc. Extensibility or scalability is the ability to extend the system with minimal efforts and risk.
The OOAD iterative and incremental development process is followed in this research instead of the rigid waterfall development process. The reason is that the iterative model allows parallel runs across all the stages of development with incremental knowledge process.
The activities involved in the OOAD include:

- Requirements engineering where all requirements to understand the decision process is gathered
- Object-oriented analysis of the system by organising the gathered requirements as objects and identify the interactions that exist between the system and the environment.
- The object-oriented design involves how the system is built, taking into consideration software architecture, object's interface design and exception handling.

Language Specification with the Unified Modelling Language

From the considerations on various specification languages that provide means of formal communication among collaborators in Section 2.11.7, the UML presents suitable features to support the development of the framework/methodology. UML advances good design patterns that could be reused to address future problems in the knowledge domain (Bersini, 2012). Therefore, UML diagrams are adopted and applied throughout to visualise the modelling of the structure of the system's elements, actors' behaviours, and interactions. The four UML diagrams used in this research are the Class diagram which is used to express the object-oriented views of the system, while others such as Use case diagram, Activity diagram are used to visualise the travellers' behaviours. To understand how the UML diagrams are employed, the next section explains the application using a library management system as an example.

(a) Use case Diagrams

The use case is a type of UML diagram that is useful in the analysis stage of the system design. It assists in the requirements analysis and high-level design; and useful for reverse engineering by describing the interaction of actors with the systems. A use case diagram consists of four elements: (1) the system; (2) actors which are agents and objects; (3) use cases that indicate actions performed by the actors and the use cases; (4) relationship between and among the actors and the use case.

Figure 3.3 is an example of a use case diagram of an online library public access catalogue. There are two actors (the *Library user* and the *Librarian*), and four use cases (*manage account, search catalogue, reserve item*, and *renew item*). It is important to mention that, in Computer Science, actors interact with the system from outside, as shown in Figure 3.3, but in Social Science and HF, actors are part and operated within a system. Therefore, in the subsequent application of Use case diagrams in this research, actors will be included within the system.

A use case is shown as an oval and placed inside the rectangle which represents the system. The actor is depicted as a stick figure, and the relationships between a use case and an actor are represented by a straight line.

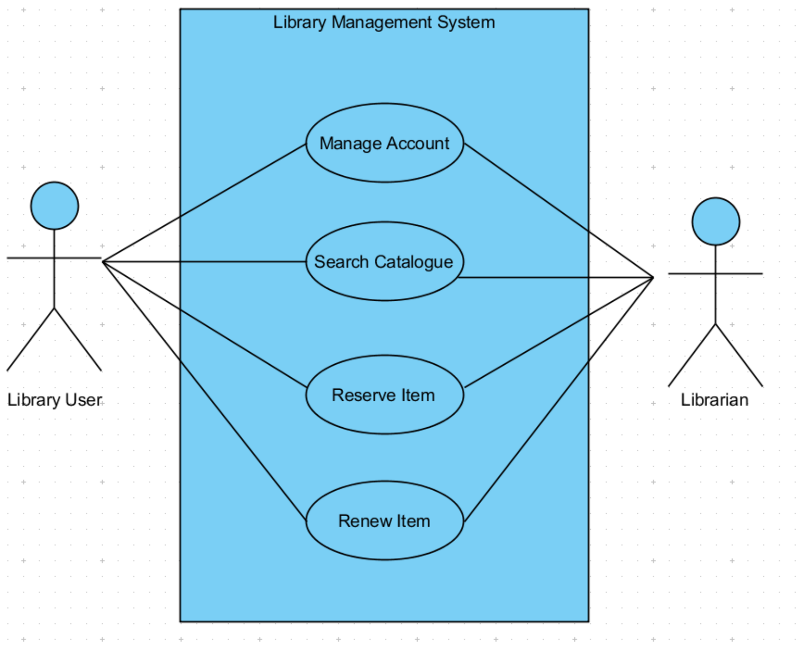

Figure 3.3: Use case diagram for a Library Management System

(b) Class Diagrams

Class diagrams represent the static view of an application and the structure of the designed system. They specify an objects' internal data and representations as well as define the operations the object can perform. Figure 3.4 is an example of LibraryUser class of the library management system example. The Library class has three attributes (*id, name, history*) and can perform three operations (*search catalogue, reserve item, renew item*).

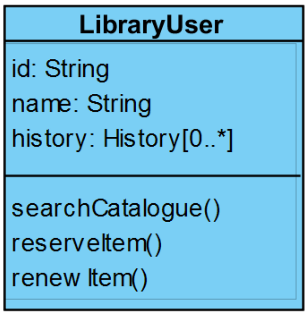

Figure 3.4: Library user class diagram (A part of Library Management System)

The data types of each attribute are listed right after its name, separated by a colon (*id, name, history*) and have types (*String, String, and Array of History*).

In the Library management system (LMS) there are many classes, and they have a relationship with each other. Figure 3.5 shows four essential types of class relationships: *generalisation, composition, association* and *aggregation*.

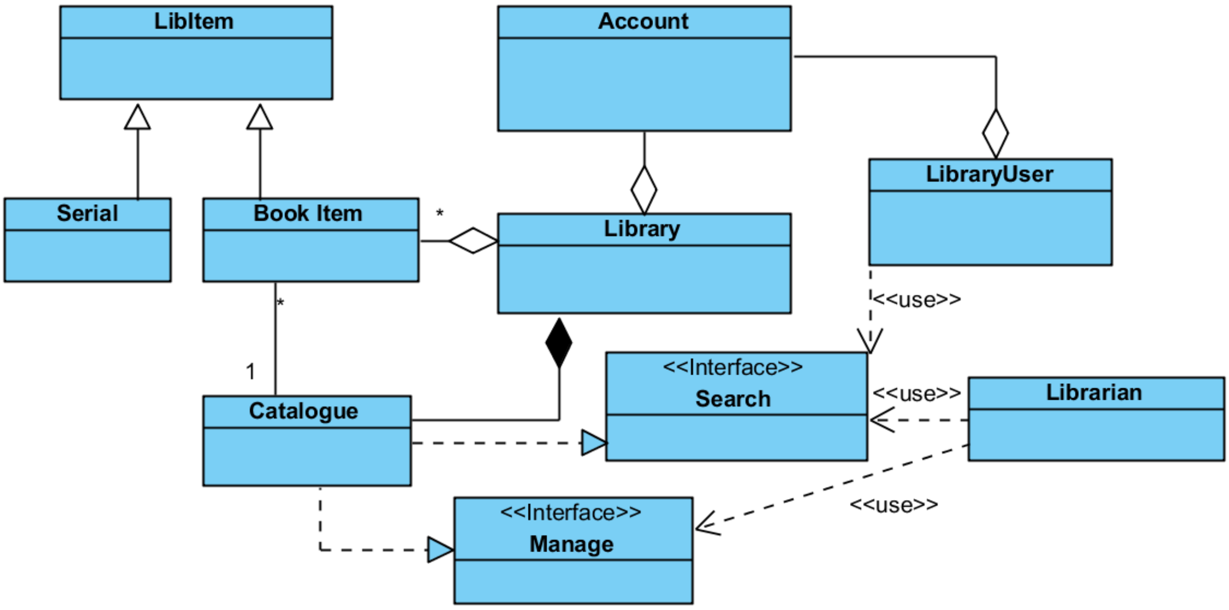

Figure 3.5: Class diagram of the Library Management System

- Generalisation expresses the inheritance relationship between a more general class (superclass) and a more specific class (subclass). The subclass inherits the structure and behaviour of the superclass but still has its own attributes and behaviour. In

Figure 3.5, Library items (LibItem) is a more general form of all items in the library from which specific library items such as book item, audio, periodicals inherit.

- Association shows that there is a link between the two classes. It is usually drawn as a solid line connecting the two classes involved. In Figure 3.5, Book item and Catalogue have an association relationship. The multiplicity (1…*) indicates the 1-to-many relationship in which one catalogue stores information about many books
- Aggregation and composition are binary association representing some whole/part relationship in a system, which mean one class is a part of another class. Aggregation implies a relationship where the child can exist independent of the parent. In Figure 3.5, book item can exist outside a library even when the library does not exist. In a composition relationship, the child cannot exist independent of the parent. From the figure above, a catalogue system will not exist outside a library.

(c) State Machine Diagrams

The state machine diagram is a behaviour diagram that describes different states of a system and the transitions between them (Bersini, 2012). It models the dynamic nature of an object within a system. Some major elements of the State machine diagram include:

- An initial state: a marker for the first state in the process, shown by a filled circle.
- A final state: a circle with a dot in it that indicates that a process is terminated.
- States: rounded rectangles.
- Transitions: an arrow from one state to another that indicates a changing state.

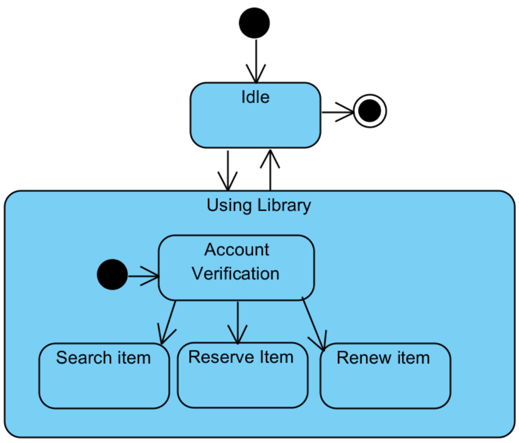

Figure 3.6: A State machine diagram of a Library Management System

Figure 3.6 shows the state machine diagram for library user class, which has two main states: “Idle”, and “Using Library” composite state. A library user can either be in the two states. In the “Using Library” state, there are four sub-states: “Account Verification”, “Search item”, “Reserve Item”, and “Renew item”. When a user wants to use the library, the transition from “idle” to “Using Library” is triggered. When in “Using library”, the initial sub-state is “Account verification”. After successful verification, depending on the action the user is willing to take among the three alternatives: “Search item”, “reserve item”, or “Renew item”. When a user completes the operation, a transition triggers, and the system goes to “Idle” state. The transition from the “Idle” state to the final state represents when the user exits the library.

(d) Activity Diagrams

Activity diagrams describe the flow of control, focus on the activities to be performed and the parties responsible for the performance of those activities. It is used to describe the dynamic aspect (behavioural) of the system or the system as a whole (depending on the complexity of the system).

Basic elements of activities diagrams include:

- An initial node: a filled circle.
- A final node: a filled circle inside a slightly larger unfilled circle.
- Actions: rounded rectangles.
- Decision nodes: diamond shapes with incoming and outgoing arrows
- Edge (Control flow): edges represented by arrows, connect the individual components of activity diagrams and illustrate the control of activity.
- Fork: a synchronisation bar for the branching of flows in two or more parallel flows depicted as a thick horizontal or vertical line.
- Join: a synchronisation bar for the consolidation of two or more parallel flows depicted as a thick horizontal or vertical line.

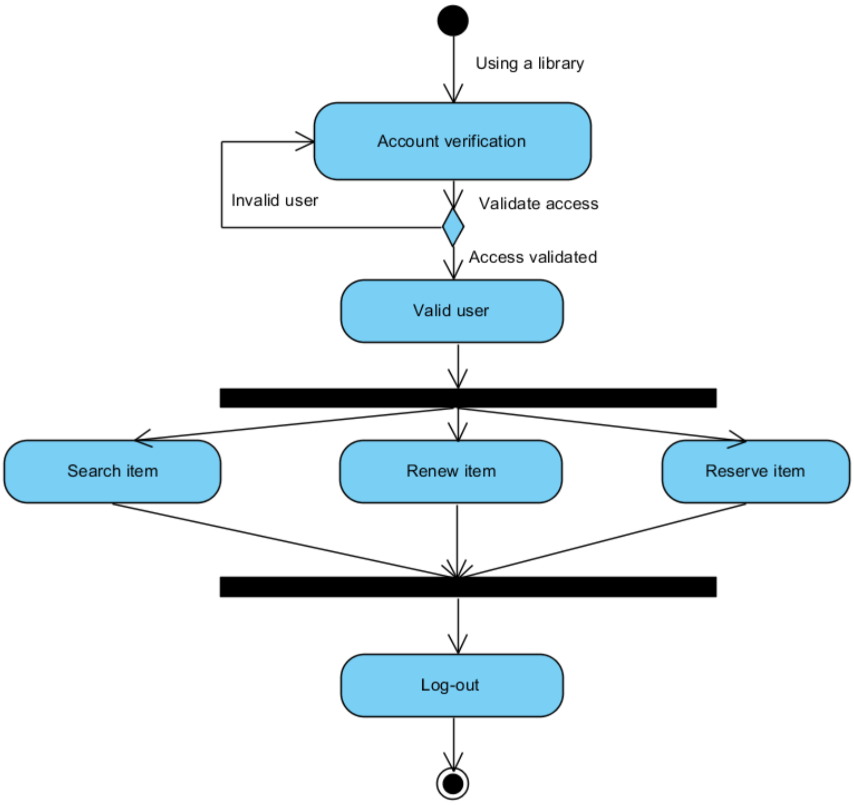

Figure 3.7: Activity diagram of a Library Management System

Figure 3.7 shows an activity diagram of a library management system. To make use of a library (i.e., "Using a Library") a library user performs "account verification" action. The verification will be carried out by the library management system. If the detail is wrong, access will be denied, and the user's access denied. Otherwise, the user proceeds to perform any of the three operations: “Search item”,” Renew item”, “Reserve Item”. After the successful operations, the user logs out of the system and the system goes to the final node.

3.4.5 Simulation Software

In order to develop an ABSS toolkit and based on the in-depth analysis of the simulation environment provided in Section 2.11.5, this research adopts Repast Simphony (https://repast.github.io) due to its architectural design that is based on central principles such as OOP, agents social networking and provision of contexts and projections that allow flexible environments for agents to participate in different networks (Collier & North, 2013).

Repast Simphony works on the Eclipse integrated development environment (IDE) (https://www.eclipse.org/ide/) which is the traditional Java programming environment. An IDE is a software that provides facilities (such as a source code editor, a compiler, a debugger, build automation tools) to maximise programmers productivity during software development. Repast also has a wide modelling capacity, scalability, and wide scope of applicability in many domains such as ecology, sociology, social sciences, and many other disciplines (Abar *et al.,* 2017). Repast is suitable for ABM toolkits development that supports the “framework and library” paradigm where the framework provides a set of standard concepts for designing and describing ABMs and the library of software implement the framework and provide simulation tools.

3.5 Summary

This chapter described the strategy for research development and methodological choice of various tools to be used to achieve the research aim. It explains the methods and tools to accomplish the development of the framework presented in Chapter 4 which forms part of the methodology discussed in Chapter 5. The domain-specific tools including the CWA, CMA and Consumat approach are chosen and the design pattern follows the adoption of SE practices and principles. The CWA is the main analytic tool for the system’s environment and the Consumat approach is the core of the decision-making component of the methodology, both form the components of the framework. The CMA evaluates individual travellers’ affective display regarding their perception of the transport system under investigation. The SE-UML and OO principles and practice provide a collaborative structured software development approach for the methodology. The overview of examples of problems where the proposed framework/methodology are later used in the thesis is presented. The choice of software for the development of the library of the framework into templates was discussed. The next chapter presents the framework structure developed with the tools discussed in this chapter.

4 Modal Shift Framework: An Overview

This chapter presents the Modal Shift Framework and its components. First, Section 4.1 discusses the principle behind the framework development. Section 4.2 presents a description of the framework and its elements. The reflections on the framework novelty and how it addresses the research objectives are presented in Section 4.3. The summary of the chapter is presented in Section 4.4.

4.1 Framework Development Principle

In the transport system, a number of ergonomic factors that discourage car users to shift mode to public transport in most of their journeys had been identified by experts including Stanton *et al.* (2013) and Derek Halden Consultancy (2003). These factors are associated with psychological variables that promote travellers' unwillingness to switch to public transport (Mann & Abraham, 2006; Gardner & Abraham, 2007). A framework is presented to serve as a standard conceptual tool to model modal shift in the transport system and to provide experts from different disciplines the opportunity to model from different perspectives. It also promotes the exchange of ideas for robust solutions to problems.

The principle that guides the development of the framework is that the perceived impact of a challenge (*perception*) in the transport environment motivates stakeholders (i.e. transport manager, policymaker) into the process of investigating the causes with a view to finding solutions to the problem. The investigative process involves fact-finding (*knowledge gathering*) about the causes of the problem and subsequent development of strategies for solving the problem (*strategies development and policy formulation*). The introduction of the developed solution into the transport environment as intervention (*strategic interventions*) coupled with interactions among travellers is believed to impact on their experiences. However, the variability in travellers' nature regarding individual needs, abilities, and interactions are factors that determine how they respond to the interventions provided. Moreover, whatever behaviours are chosen by individual travellers within the transport system is felt within the environment.

4.2 Description of the Modal Shift Framework and Framework's Elements

The Modal Shift framework (MOSH) discussed in this section is an integration of two major tools: The *Cognitive Work Analysis* (CWA) (detailed in Section 2.11.1), and the *Agent Decision Module* inspired by the Consumat approach (Section 2.11.4), embedded in the *system environment*. The description of the framework's elements and the relationships that exist among the elements are discussed in the succeeding sections.

4.2.1 The Sociotechnical Environment

The sociotechnical transport system environment is the outer box of the diagram shown in *Figure* 4.1. It is derived from and operated within the larger natural environment (Jager, 2000).

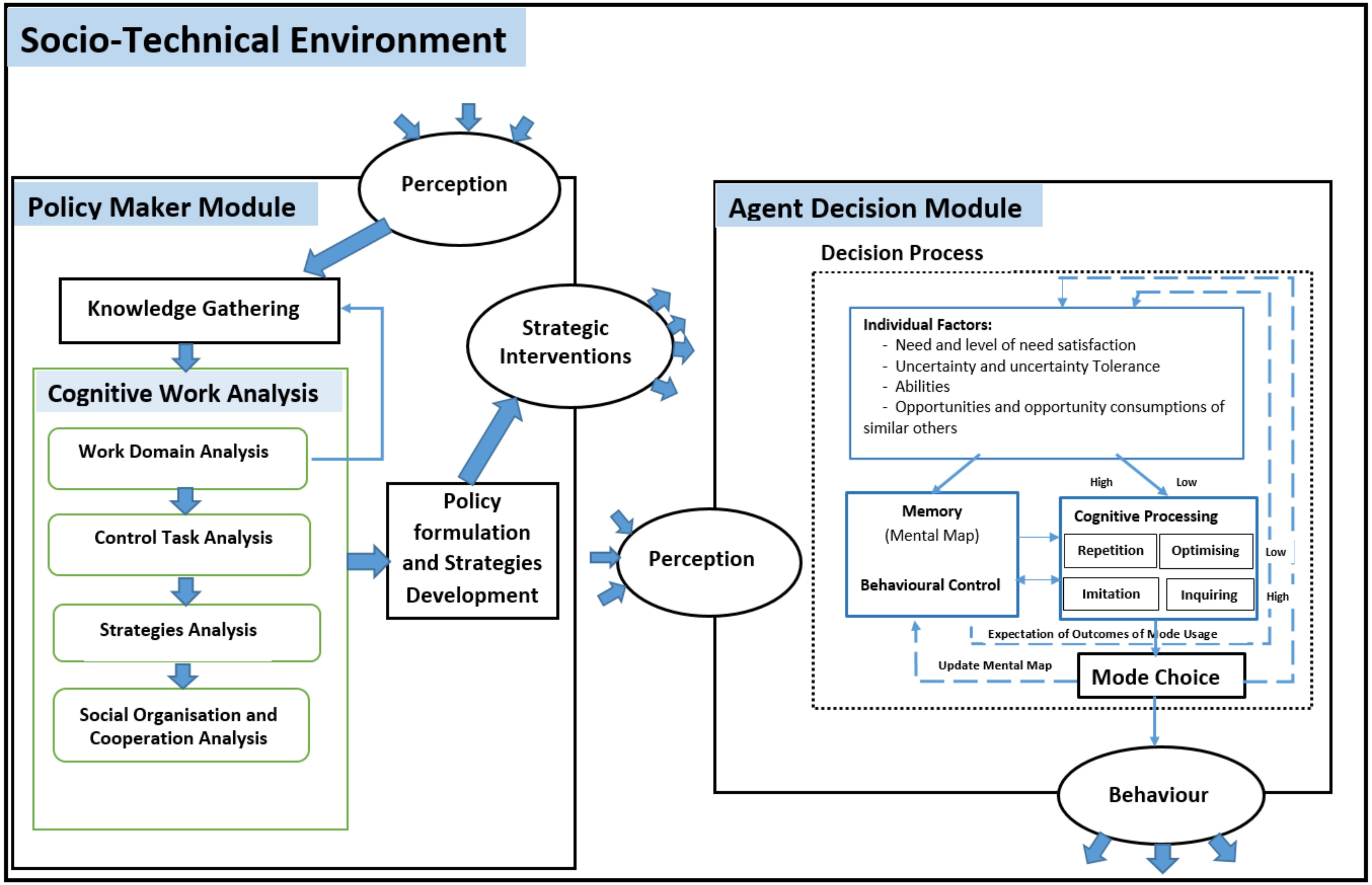

Figure *4.1*: The Modal Shift Framework

The transport environment within which the policymaker and the individual travellers operate consists of technology (e.g., transport system infrastructure), economy, demography, cultures, and institutions. According to Jager (2000), the available resources within the transport environment are applicable to all travellers irrespective of their status. Hence, making the environment the decision context of the travellers.

4.2.2 Agents' Decision-Making Element

The second component (i.e., the inner right box in *Figure* 4.1) is the *Agent Decision Module.* It models travellers' decision process within the system using the key behaviour's driving factors. The components and processes in the Agent Decision-making environment are: the perception, the agents' decision module, and agents' behaviour.

Perception

Travellers' perception is their views or beliefs regarding the travel mode which they intend to use for their journeys. The view of a traveller is strongly influenced by micro-level factors such as the travellers' needs and abilities.

Agent Decision Module has micro-level factors, memory and behavioural control as well as cognitive processing.

Micro-level factors are the individual travellers' attributes and traits that include their needs, the level of needs satisfaction, the uncertainties in the decision process, the tolerance regarding uncertainties, the ambition level, and their abilities to travel with a given travel mode. These factors with the travellers' memory content play roles in the decision process.

Memory and behavioural control is the box (within the agent's decision module) that represents the travellers' memory of personal characteristics, previous experiences with the system, and memory of other travellers' experiences. It also has *Behavioural Control* which is the ability possessed by the traveller, and the ability demanded (e.g. financial, physical, cognitive, and affective) to make a journey with a travel mode

Cognitive Processing is the decision processing box that contains the core of the strategy employed by travellers to evaluate the available travel modes. The process depends on the ratio of the travellers' *level of needs satisfaction/ambition level* as well as the ratio of *uncertainty/uncertainty-tolerance* level. After a traveller has evaluated its mental state, depending on whether it is generally *satisfied* and/or *uncertain* with the chosen travel mode, the traveller decides on which information-seeking strategy to select. The four information-seeking strategies available for selection mirror the cognitive processing of agents in the original Consumat framework. In general, an *unsatisfied* state of a traveller results in a search for new information, while a state of being *uncertain* causes a traveller to explore what other travellers do to make use of the travel mode. When a traveller is *satisfied* and *certain* with its current chosen travel mode, the traveller *repeats* (current behaviour) the use of the travel mode without considering alternative modes. A *satisfied* and *uncertain* traveller engages in social comparison to *imitate* the behaviour of other similar peers. These similar others are those that a traveller has strong links with and that can easily be accessed. *Unsatisfied* but *certain* travellers *optimise their* own knowledge by seeking new information through media, adverts, etc. When a traveller is both *unsatisfied* and *uncertain*, such traveller seeks new information by *inquiring* from others about their travel modes. The outcome of the evaluation process determines the decision of a traveller on which behaviour or travel mode to choose.

Behaviour

After a decision has been made on a preferred travel mode, a traveller engages in the behaviour of making the journey with a travel mode. The resultant effect of individual travellers' actions which could be positive or negative (e.g. road congestions due to many car users, rise in CO_2 emissions) would be felt in the environment. The effect of the behaviours triggers policymaker activities.

4.2.3 The Policymaker Element

It is important to state that the position of the policymaker in the framework is different from that of the Traveller agent who frequently makes decisions about the travel mode to choose. The activities of policymaker only apply when there is perceived (un)pleasant situations in the transport environment.

The policymaker module consists of the activities to be performed and processes to be taken by the stakeholders to achieve the understanding of the transport system's constraints on the traveller's mode choice decisions. The activities within this module include *Knowledge Gathering*, analytic process with the *Cognitive Work Analysis,* and *Policy formulation and Strategies Development* (the rectangular boxes). The two processes in the module are the problem's *Perception* and *Strategic Interventions* (the ovals). The *policymaker module* provides a means of gaining insights into factors that influence travellers' behaviour and the relationship that exists among those factors. The outcome of the analysis provides information to support the development of policies and the formulation of strategies for interventions to the identified problems. The nudge from the interventions coupled with the effect of social interactions among the travellers influences travellers' subsequent decisions within the system.

Perception

The sensing of (un)pleasant situations in the transport system environment by the stakeholders which call for improvement is the perception process of the policymaker module. For example, the recent global attention on the rise in CO_2 level in the atmosphere is an example of perceived issues of concern that require investigation.

Knowledge Gathering

An investigation into how the perceived challenges can be resolved involves gathering relevant information regarding the causes. Different data gathering techniques such as focus group meetings, observations, interviews, etc., supported by the WDA -AH modelling tools would be involved at this stage. The feedback arrow in *Figure* 4.1 shows that there are interactions and iterative processes between the WDA and the knowledge gathering process.

The iteration is to ensure that adequate relevant objects and resources that should be included in the investigation process are not left out.

<u>Cognitive Work Analysis</u>

The CWA component of the framework involves four phases: work *domain analysis, control task analysis, strategies analysis*, and *social organisation cooperation analysis* which all offer formative analytic supports to the system's environment.

The *work domain analysis* section of the CWA 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 on travellers' mode choice process. The *control task analysis* (ConTA) relies on the qualitative data from the survey and general knowledge of the problem's area to model the functions that a traveller can perform in various situations to achieve a purpose independently of how it is being conducted or undertaken. The *strategies analysis* (SA) models different possible ways by which a function can be performed by the traveller focussing on the flexibility of performing the functions in different ways. The freedom and flexibility allow travellers to adapt and select a way of achieving an end-state that is most appropriate in each situation. Such new strategies would increase the possibilities of putting the system to better use. At the *social organisation and cooperation analysis (SOCA)* stage, the descriptive data from the survey supported with the identified stereotypes provides information on different categories of travellers that are present within the population, and that have different needs.

<u>The Policy formulation and Strategies Development</u>

The strategies for behaviour change are developed and applied as interventions into the transport system environment. The intervention when encountered by the travellers through curiosity during the information-seeking process increases travellers' knowledge of the environment and hence improve their experiences.
For example, provision for the needs of a mobility-impaired traveller to access a travel mode as an able-bodied counterpart could stimulate their behaviour towards using the travel mode.

The second objective of this research is accomplished with the development of MOSH framework discussed in this chapter. The framework is one of the contributions of the research to knowledge.

4.3 Reflection on the Modal Shift Framework

In comparison with the Agent-Oriented model development frameworks considered in Section 2.9, the novelty of MOSH framework emerges in the following areas:

1) its capabilities to model dynamic traveller agents as they traverse the transport system environment. None of the reviewed development frameworks/methodologies captures the spatial and temporal perception of agents in a dynamic environment. The incorporation of CWA into the MOSH framework's modelling process offers the needed support to model the environment from the perspective of a dynamic agent.

2) the framework provides systematic support for policy formulation and strategic interventions to stimulate travellers' behaviour.

Furthermore, the reflection on the MOSH framework is done along three perspectives:
a) the conceptual soundness of the framework potential to develop more realistic modal shift agent-based models. The facts that the major components that form the framework are well researched and established tools and techniques from various domains of knowledge which have matured through many different applications over the years add to the conceptual soundness of the MOSH framework.
b) the completeness and conciseness of its adequacy in modelling modal shift problems with limited components. The pilot case study model from the initial design of the framework and the insights from the discussions with experts led to the rearrangement and removal of redundant concepts in the initial design of the framework. This adds to the conciseness and completeness of the framework. In the initial framework design, the problem *environment* is presented as a distinct entity of the system in which only the agent operates. This framework version was used to conceptualise a prototype model that used a dataset acquired from the UK's National Rail Passenger Survey (NRPS Spring 2015: Wave 32) (Transport Focus, 2016), reported in Faboya *et al.* (2017) (see Appendix H). In the prototype study, the policymaker's role is initially unclear and there is limited clarity in the interactions that exist among the travellers, policymakers and the transport environment.
c) the usefulness of the framework that shows that this modelling approach brings ABM within the reach of interested non-experts from other domains. The incorporation of the Consumat approach to model travellers' mode choice provides a means of modelling individuals.

The above features of the Modal shift framework adequately address the shortcomings in the existing model development frameworks/methodologies. This novel approach allows for in-depth modelling of individual travellers and provides an opportunity to stimulate their behaviours.

4.4 Summary

The framework development processes and the design principles are discussed in this chapter. The design principle is guided by the aim of the research and the objectives to be accomplished. The development process includes the initial idea that was used to model a prototype study that revealed some limitations in the design that was later addressed in the improved final version of the framework. The description of the final MOSH framework and the detailed explanation of its elements and their relationship as well as how they are linked to achieving the intended purpose was also discussed. General reflections on the MOSH framework including its novelty were discussed. Lastly, as one of the major contributions of this research to knowledge, the development of the framework into a methodology that included the processes and procedures to achieve the aim of the research is presented in the next chapter.

5 Modal Shift Methodology: An Overview

This chapter provides details about the MOSH methodology and the methodology process map. The need for the development of the Framework to methodology is presented in Section 5.1. Section 5.2 discusses the MOSH methodology process map that includes the system development lifecycle. Section 5.3 gives a detailed description of the stages involved in the methodology. The reflection on the novelty of the methodology is highlighted in Section 5.4. A chapter summary is given in Section 5.5.

5.1 From a Framework to a Methodology

The framework developed in Chapter 4 is part of the modal shift methodology presented in this chapter. The framework is the first step in the process map to conceptualise travellers' activities and decision-making process at the system analysis stage of the methodology. To achieve the research aim of providing collaborative support among experts from different backgrounds, and to extend the strength of the framework to model low-level details of the travellers, the methodology includes the following processes and procedures: 1) the use of SE tools and practices to provide a structured transparent modelling approach and standard formal language of communication among a project group; 2) techniques to investigate details about travellers' attributes (e.g. abilities), the factors that form the body of their decision, and the significance of each of the decision factors on travellers choice; 3) a generic format for data collection; 4) the technique to derive travellers' affective display (emotional state) at various stages of their journey in the transport system environment.

The overview of the MOSH methodology's process map is presented in the following section.

However, it is important to state that when referring to the combination of MOSH framework and MOSH methodology in this thesis, the term **MOSH toolkit** would be used.

5.2 The Overview of the Methodology Process Map

Figure 5.1 shows the MOSH methodology development process map which includes the aspects of the methodology that has general applications and the aspect that has specific applications to modal shift problems. The MOSH methodology consists of four layers and seven stages that serve different purposes.

The layers are:

- *The development process flow layer* is indicated by the middle "light-blue one-directional arrow" bounded by deep blue colour. The process flow shows the direction of execution in a study (left to right on the top and right to left on the bottom part of the diagram). It spans the seven stages of the process map in one direction starting from the *system analysis,* to the *experimental output presentation and usage* stage.
- *The data flow layer* is indicated with brown colour arrows in the diagram. It shows the direction of raw data (e.g. survey data) flow from the stage where it is generated to the stage that uses the data or flow in between two phases that require the data.

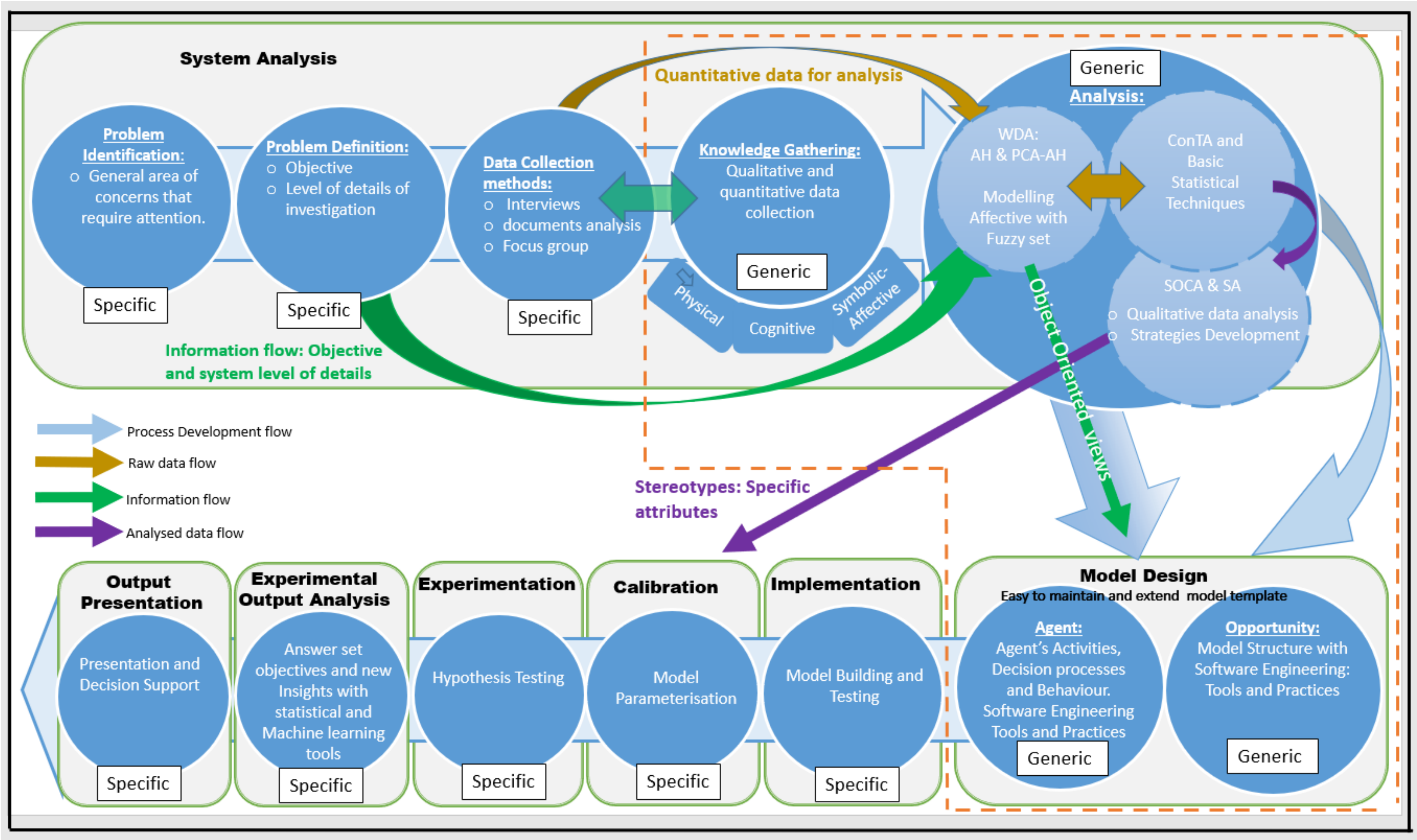

Figure 5.1: The Modal Shift Methodology Development Process Map Diagram.

- *The information flow layer* has a green arrow showing the direction of information flow between phases or from one phase to another within the study. The information flow layer carries contents needed to support and inform the study's direction such as the aim of the study and the level of details being investigated.

- *The analysed data flow layer* is indicated with the purple colour arrows in the diagram. It shows the direction of the flow of analysed data into phases where it is used.

There are two major sections in the process map diagram shown in Figure 5.1: the *generic section* bounded with the brown dotted lines, and the *specific section* in the unbounded areas.

- *The generic* section of the methodology comprises all stages and phases that can be adapted in all specific cases. The phases and stages that have general applications are labelled 'Generic' in the process map diagram. It covers a section of the *System analysis stage* (i.e., *Knowledge gathering* and *cognitive work analysis* phases) and the whole of the *design stage* of the methodology process map. Each of the generic sections is designed into templates to be extended and reused by interested stakeholders as explained in sections 5.3.1 and 5.3.2.

- The section of the methodology for *specific* applications are the phases and stages that are meant to be executed and tailored to a well-defined problem. These sections are labelled 'Specific' in the process map diagram.

The next section describes the stages of the methodology.

5.3 Description of the MOSH Methodology Stages

The concepts and relations that constitute the MOSH methodology are introduced in the context of an illustrative example: Understanding individual response to decision factors. A study on the travel experiences regarding the abilities of a set of travellers to a university to satisfy the travel requirements (i.e., physical, cognitive, and affective) considerations to make use of alternative travel modes.

The simplified version of the illustrative example is used to explain how a modal shift problem can be developed using the MOSH framework/methodology in the following section. The main stages and the phases of the methodology process map are discussed as they appear in Figure 5.1.

5.3.1 System Analysis Stage

The four major phases in the system analysis stage are *problem identification, problem definition, knowledge gathering* and *analysis*.

5.3.1.1 Problem Identification

From the illustrative example, the existing difficulties in identifying the contributions of decision factors (Wardman *et al.,* 2001) that constitute travellers mode choice decision is the identified problem that needs investigation. Travellers' abilities to use a travel mode is influenced by both *ergonomics and psychological factors.* Investigations into some of these factors have remained implicit due to the limited capability of the modelling methodology used (Mann & Abraham, 2006; Steg *et al.*, 2001; Steg, 2005) in the investigation. To be able to stimulate travellers' behaviours in mode choice, a detailed understanding of the factors and their contributions are necessary.

5.3.1.2 Definition of Problem

The objective of the illustrative example is to understand individual travellers' responses to the travel requirement considerations in their decision making. The questions to answer are:

- what constitute the decisions made by individual travellers among the main travel requirements of physical, cognitive, and affective consideration?
- what level of considerations of these requirements are involved in the travellers' decisions?

Answering the questions will assist stakeholders to proffer appropriate strategy to stimulate the behaviour of different categories of travellers.

Also, the terminologies to convey the information about the psychological and ergonomic factors and other system's attributes within the environment are defined during problem definition. The purpose is to have an agreed convention to be used by the project's collaborators in the subsequent stages of the investigation.
In Figure 5.1, the information flow (green arrow) from the problem definition phase to the WAD-AH (within the Analysis phase) carries the defined terminologies to other stages to guide the analysis of the collected data.

5.3.1.3 Data Collection Methods and Content Definition

Suitable data collection techniques including interviews, focus group meetings, and questionnaires are used to achieve the objectives of the fact-finding process. Since it is not feasible to consider all the resources and physical objects within the transport system, the abstraction hierarchy (AH) of the CWA- WDA assisted to:

(1) identify relevant transport infrastructure and facilities to be included.
(2) establish how relevant infrastructure within the transport system are related to each other and support the travellers in their journey making process.

The bi-directional information flow arrow (boxes 3 and 4 in Figure 5.1) that connects the *data collection phase* with the *knowledge gathering* phase is an iterative process that ensures the content of the questions are adequate and reflect the fundamental elements needed to answer the purpose of the problem. For instance, to reflect both the psychological and ergonomic factors affecting travellers PCA considerations in mode choice.

5.3.1.4 Knowledge Gathering

The *Knowledge gathering* phase is the first part of the methodology that has general application. In principle, it encompasses the *data collection method* phase. The two phases (boxes 3 and 4, in Figure 5.1) have been separated because the method of data collection (e.g. interview, questionnaire) and the content of the data to be collected are specific to the problem being investigated, while the format for *knowledge gathering* has a general format.

Both qualitative and quantitative data are necessary to be collected. The contents of the questions must be intuitive and psychological. It must also reflect travellers' views on the physical, cognitive and emotional demand of the travel modes. The travellers' perceptions are assessed on the importance and satisfaction of the travel mode in question. The *importance* aspect measures how important are the attributes of the travel modes being investigated and the traveller's intrinsic perception of such attributes. The *satisfaction* aspect assesses how satisfied are the travellers with their travel mode experiences. The intention of using the *importance-satisfaction* format is to provide a means of obtaining:

(1) the users' emotional perceptions of the travel modes directly from survey data and,

(2) to allow other personal traits of the travellers to be captured from the context and content of the questions.

Table 5.1 and Table 5.2 contain sample questions for the *importance* and *satisfaction* of travel modes' attributes: *information provision* and *mode's accessibility*.

i) *Question sample: How **important** are the following to your journeys on your usual travel mode?*

Table 5.1: Data collection format on the Traveller's importance on the Travel modes' attributes

	Very Unimportant	Somewhat Unimportant	Neither Important nor Unimportant	Somewhat Important	Very Important	Not Applicable
a. Information provision (e.g. timetabling)	○	○	○	○	○	○
b. Physical ability required	○	○	○	○	○	○

ii) *Question sample: How **satisfied** are you with the following on your typical journey?*

Table 5.2: Data collection format on Traveller's satisfaction on the Travel modes' attributes.

	Very Unsatisfied	Somewhat Unsatisfied	Neither Satisfied nor Unsatisfied	Somewhat Satisfied	Very Satisfied	Not Applicable
a. Ease of accessing information on your travel mode. (e.g. timetabling, website)	○	○	○	○	○	○
b. Ease of getting on and off your travel mode	○	○	○	○	○	○

Travellers' perceptions regarding their situations and the functions they can perform within the transport system have physical, cognitive and affective aspects. From the sample questions, items '*a*', in both tables are about the travellers' perception of the travel mode's information provision. The question in item '*a*' can be seen to focus on the traveller's cognitive ability to access information to use the travel mode. Also, item '*b*' in both tables are related to the physical ability to use the travel mode hence, it focuses on traveller's physical consideration of the travel mode. Each of the two questions has emotional attachments (affective display) that come from the travellers' (un)pleasant experiences.

5.3.1.5 The Analysis Phase

The *analysis phase* of the System Analysis stage is the second phase that has general application in the methodology. It involves: 1) the constructions of AH, ConTA SA and SOCA; 2) Analysis of descriptive survey data to derive the emotional state of travellers at the various stages of their journey, and 3) Analysis of qualitative data.

The Construction of Abstraction Hierarchy

For illustration, the AH in Figure 5.2 shows how both the traditional AH and extended PCA-AH could be constructed for a traveller whose needs include an efficient journey (e.g., time, costs).

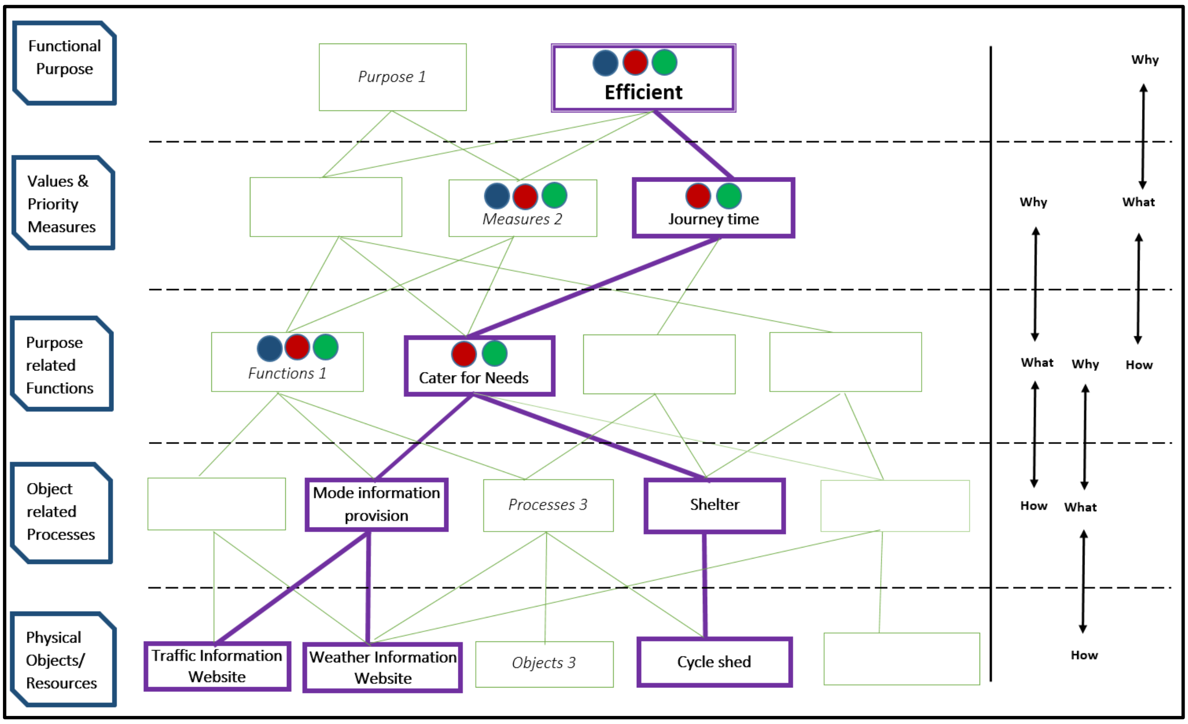

Figure 5.2: The Abstraction Hierarchy adapted from Vicente, 1999; Stanton et al., 2013)

The AH is constructed with the indications of travellers' perception of the physical, cognitive, and affective (PCA) considerations. The traditional AH has the same structure as the AH shown in Figure 5.2 except for the solid filled coloured circles. The solid filled coloured circles represent the presence of the travellers' PCA considerations of their modes. The red circle indicates the presence of *cognitive* consideration, the solid filled blue circle stands for *physical* consideration in travellers' perceptions of their environment. The solid filled green circle represents the emotional (i.e. the *affective display)* consideration in the travellers' decision-making. However, it is important to state that as the PCA consideration varies according to individual travellers, the weight of colours that indicate these factors also vary.

To explain how the contents of the hierarchy are constructed for the illustrative example, the *'how-what-why*' triads (Section 2.11.1) is used as follows: Following the highlighted links in

Figure 5.2 and starting from the bottom of the AH, if the *'mode information provision'* at the *Object related processes* level is taken as *'what'*, all connected nodes below at the *physical object* level (i.e. traffic information website, cycle shed) should provide *'how'* the *'mode information provision'* is achieved. The level above, i.e. '*purpose related functions*' level should provide information on *'why'* the objects are necessary for the system, that is, taking care of the information needs of the user.

Starting from the bottom of the hierarchy, the ***physical objects and resources*** level is populated with infrastructure and resources available in the University transport system environment. For illustration purpose, resources such as *traffic information website, weather information website* and *cycle shed* have been included. The ***object-related process*** level indicates that the *physical resources (e.g. traffic information website) is* used for the travel mode *general information provision* while the *cycle shed* is for *shelter provision*.

It is important to state that the *physical resources* (first level) and the processes of using the resources (second level) are independent of the traveller. The heterogeneity in traveller's abilities regarding their PCA considerations in decision making is considered and investigated at the remaining three levels of the hierarchy (i.e. the *purpose related functions, values and priority measures and functional purpose levels).* This is because decision making at these levels is travellers' abilities dependent.

The ***Purpose related functions*** level has the general purposes necessary to achieve a task. For instance, the general purpose of *information provision* and *shelter provision* in the *object-related process* level is to cater for the information and shelter needs of the travellers. The PCA representation in the *Purpose related functions* level for example only includes the cognitive and affective indications (i.e. the red and green colours). This is because a traveller applies cognition while accessing relevant information regarding the travel mode with little or no physical ability requirements. There is also an associated emotional state for the satisfaction derived from the achievement of the objective. However, in some other situations such as a pedestrian or cyclist finding a suitable route may require the consideration for the physical effort to achieve the objective hence, in such cases the blue colour circle would be included.

The ***values and priority measures*** is the fourth level from the bottom of the AH that has the criteria to measure how a system progresses towards its functional purposes. From the illustrative example, *Journey-time* is one of the criteria to measure travel mode efficiency as shown in Figure 5.2.
The representation of the PCA consideration at this level indicates that the link from the lower level into the *Journey-time* involves cognitive and affective considerations. This is responsible for the presence of a solid red and green circle as shown in the figure. However, in some cases, there may be a need to indicate the physical component with a solid blue circle as shown in the dummy node *measure 2.* In the final analysis, some nodes contain the three colours indicators while others have fewer colours.

The topmost level of the hierarchy is the ***functional purpose*** that represents the transport system's purpose. In our example, part of the purpose of the University transport system is to satisfy traveller's needs for efficient travel (e.g., time, costs). The *Journey-time* measures mentioned above is one of the criteria to evaluate time efficiency. The indication of the PCA considerations is also represented at the functional purpose level.

The Control Task Analysis and the Construction of Contextual Activity Template

The contextual activity template (CAT) is built from the travellers' identified recurring activities such as 'driving', and 'checking mode information'. Figure 5.3 is a sample CAT from the illustrative example.

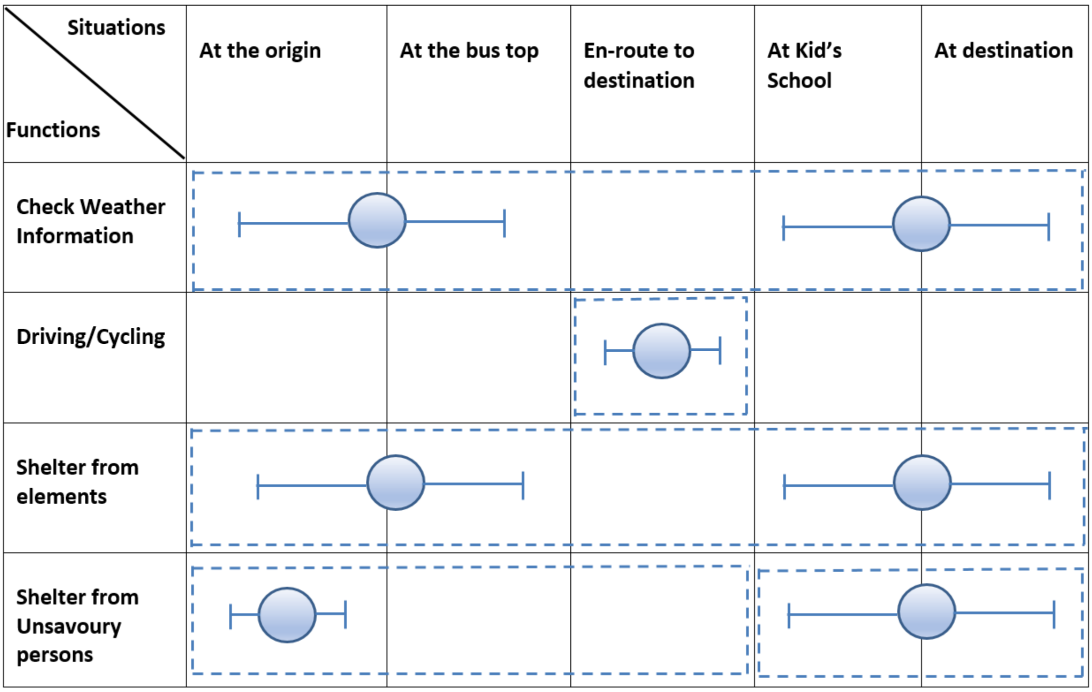

Figure 5.3: The Contextual Activity Template (CAT)

The figure shows the situations that a traveller can be such as *at the origin*, *at the bus stop*, *at kid's school,* etc., and the functions that the situations support including *Check Weather Information, Driving/Cycling,* etc. In the situation *'En-route to destination'*, functions such as *'Checking Weather Information', 'Shelter from elements'* and *'Shelter from unsavoury persons'* could occur but typically do not (reason for the dashed box only). The same can be said about *'at the bus stop'* situation, where *'Shelter from unsavoury persons'* function could occur but does not occur. However, the function *'Driving/Cycling'* cannot occur in all situations except while *en-route to destination therefore,* under this function, all situations do not have both the dashed box and the ball except at the combination of *'En-route to destination'* situation. It implies that the cells without the circle and the boxes are potentially unnecessary.

The Strategies Analysis: the means to perform the same function differently

Different ways of performing the same function emerge from participants' responses to questions (given individual level of expertise or ability) and from various suggestions made by the participants to solving a problem other than the natural way of performing the functions. For instance, accessing relevant information about a travel mode could be improved with the provision of access to offline information outside the coverage areas. The emerging possible ways are introduced as part of the interventions to increase the flexibility of performing the same function in different ways. The increased flexibility may increase the likelihood of more travellers adopting the less preferred mode.

Social Organisation and Cooperative Analysis: Understanding Individual Needs and Requirements

The *Social Organisation and Cooperation Analysis (SOCA)* provides more understanding of the natural structure in the dataset beyond simple categorisation (e.g., traveller type). The stereotype learning process is informed by the aim and scope of the problem. The descriptive survey data and the output from the CAT with relevant statistical techniques such as clustering algorithms help in identifying the groups of individual travellers with different needs within a population.

5.3.1.6 Algorithms to Derive Travellers' Physical, Cognitive and Affective Perception from Survey Data

The detailed analytic processes of how each of the travellers' attributes to be investigated are derived from the survey data are part of the Analysis phase. In the following section, the traveller's PCA perceptions are derived from the survey data.

Physical and Cognitive Perceptions from Survey Data

The travellers' physical and cognitive perceptions of the travel mode's concepts are derived as follows:

Questions on each of the travel mode's concepts (e.g. travel mode's information provision) are examined to ascertain if they answer a question related to physical (e.g., mobility), cognitive (mental) or both activities. For example, the question "*How satisfied are you with the ease of accessing information about your travel mode …?*" is more appropriate to be classified as a cognitive assessment question than a physical assessment question. Following this technique, all travel mode's concepts to be investigated are classified accordingly to be either physically or cognitively perceived. However, where more than one question is related to a concept, the mean of the responses in all questions regarding the concept is taken.

The process is expressed as:

$$\frac{(\sum_{p=1}^{n}(y))}{n}$$ *Equation 5.1*

Where *y* is the travel mode's concept under consideration (e.g. *traffic information website* and *weather information website*, etc.); *p* represents the questions associated with *y*, and *n* is the number of related questions to the concept.

Emotional Perception from the Survey Data

The traveller's emotional perception (affective display) is also derived from the survey dataset. The traveller's responses to the questions on the *importance* and *satisfaction* of the travel mode concepts are obtained and recorded. In a situation where more than one question is related to a travel mode's concept, then Equation 5.1 applies. Following the procedure, two separate values (i.e. one for the importance and one for the satisfaction) are generated for all the travellers on each of the attributes.

Algorithm for Affective Display Generation

The two values (i.e., *importance and satisfaction*) form the two-dimensional input into the affective display generation algorithm discussed in the following:

The affective generator engine in the MOSH methodology generates the affective perception based on the expert's knowledge from the CMA (Section 2.11.3). The mapping in Table 5.3. presents the relationship between the two inputs i.e. the *Importance* (which represents the arousal) and the *satisfaction* (which represents the pleasantness). The output from each pair of crisp inputs into the system is the interception of a row and a column which produces an affective display point (emotional perception) of a traveller.

Table 5.3: Affective Generator Input Mapping

Arousal / Pleasantness	Arouse	Somewhat-Arouse	Neither-Arouse- Nor-Unaroused	Somewhat Unaroused	Unaroused
Pleasant	Excited	Enthusiastic	Pleased	Contented	Relaxed
Somewhat Pleasant	Stimulated	Elated	Happy	Comfortable	Calm
Neither-Pleasant-Nor-Unpleasant	Afraid	Anxious	Neutral	Bored	Fatigued
Somewhat Unpleasant	Angry	Frustrated	Dissatisfied	Uncomfortable	Bored
Unpleasant	Disgusted	Discontent	Disappointed	Sad	Dejected

The listing in Algorithm 5.1 shows the steps that return travellers affective perception on the respective travel mode's concept considered.

Algorithm 5.1: Algorithm for Agent's affective display generation

Algorithm to derive affective component from survey dataset

// Create a two-column table for *importance* and *satisfaction responses attributes of the alternative opportunities*
for each participant **do**
    for each x **do**   // where x is the *travel mode's concept.*
        Find the mean of $\bar{\imath}$ and $\bar{\jmath}$ $\forall$ questions related to x.   // where i is the importance and j is the satisfaction
    $x_i = \bar{\imath}$ and $x_j = \bar{\jmath}$
    end for
end for
for each x **do**   // where x is the *travel mode's concepts*
    Generate affective requirement from x_i and x_j //where x_i and x_j are crisp inputs values
    Return affective value
end for

The succeeding section discusses the procedures for qualitative data analysis.

5.3.1.7 Qualitative Analysis of survey data

Participants' responses to the open-ended textual questions are comprehensively read to gain a sense of the content and the attributed meaning to the responses. Any common textual analysis methods such as the construction of themes or grouping responses into categories can be used. The format shown in Table 5.4 contains four columns that capture participants' qualitative perceptions of their travel modes. The table is created for each of the groups found in the population.

Table 5.4: The Textual Analysis Format table

The mode concepts being investigated	Identified problems/ Problems' sub-category	Suggested Solution space	Related defined Theme
The main aspect of the transport system being investigated.	Specific constraints i.e. the travel mode's concerns to travellers (e.g. cyclist's concerns for route obstructions)	Suggested solutions provided on the transport system's constraints by the traveller.	A general description of the constraints or the measures of performance, e.g. delays).

- The first column of the table contains the travel mode concepts of concern to the travellers (e.g., information provision and accessibility).
- The second column listed the travellers' specific concerns (e.g., route obstructions).
- The third column has the solution-space that contains the suggested possible solutions made by the travellers on specific problems (e.g. fines for cycle lane obstructions).
- The fourth column contains the theme that represents a general description of a set of related problems such as *delays, reliability*. Each of the themes can also have sub-categories that present a participant's specific concerns. For instance, *bus frequency, route obstructions, bad lane marking,* etc., are specific concerns related to the theme *delays*.

The textual analysis provides two important sets of information for the study:

1) support for the development of strategy and policy formulation for interventions.
2) insights that support model experimentation.

The procedure for the policy formulation and strategies development is given in the following section.

5.3.1.8 Policy Formulation and Development of Strategies for Intervention

The policy formulation and strategies for interventions are developed from the travellers' suggested solution-space in the textual analysis table (column 3, Table 5.4) supported with the CAT output in Section 5.3.1.5. The strategies for behaviour change are evaluated with the *Values and priority measures* elements that measure the system performance. For instance, a group of cyclists may have expressed concerns about cycle lane obstructions. In the solution-space (column 3, Table 5.4), such cyclists could have suggested campaigns or imposition of fines for obstructing cycle lanes as the solution to curb road obstructions. From their suggestions, strategies such as public enlightenment can be developed to address the concern of that category of travellers.

5.3.2 The Model Design Stage

Next to the System Analysis stage in the MOSH methodology process map is the Model design stage that presents a high-level abstraction of the transport system's elements.

There are two main *Actors* and one Object in the system. The Actors are:

1) the Traveller agent which dynamically interacts with the transport system's environment and with other traveller agents within the system.
2) the Policymaker agent is the stakeholder that investigates the (un)pleasant situations regarding the activities of the travellers within the system. It formulates policies and develops strategies to address the system challenges and also applies interventions to stimulate travellers' behaviours in order to adopt alternative travel modes.

The Object is the available opportunities (i.e. travel modes from among which the traveller agent chooses.

In this thesis, the two actors in the model are simply referred to as the *traveller agent* and the *policymaker agent* and the opportunity is referred to as the *travel mode*.
In the model design, four UML diagrams are used to visualise and present the system components' design structure. These are the use case diagram, class diagram, state machine diagram and activity diagram.

5.3.2.1 Use Case Diagram

Figure 5.4 introduces a basic use case of how the traveller agent decides. Each specific case study can extend the generic decision use case by including activities that are peculiar to the situation.

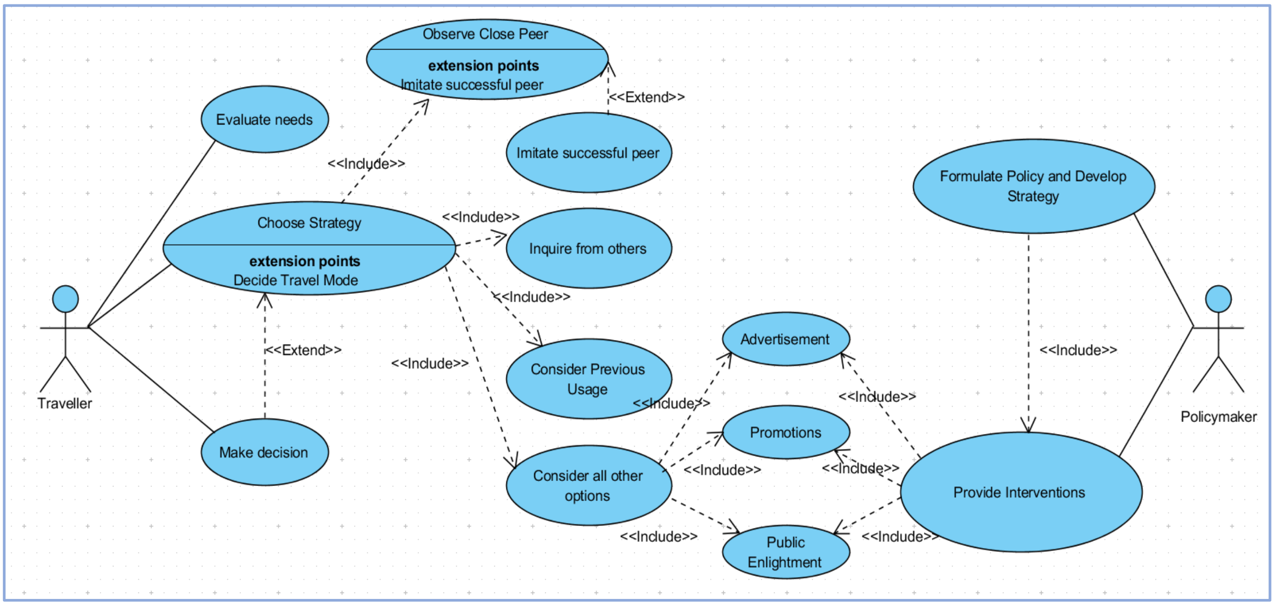

Figure 5.4: Actor's use case diagram

Figure 5.4 consists of four elements: (1) the system environment that contains the two classes of agents; (2) the Traveller agent and the policymaker; (3) the use cases that indicate actions performed by the agents; (4) relationship between the two agents and the use cases.
It is important to note a fundamental difference in the concepts of use case design in SE practices for software development and those in social simulation. In SE for software development, actors interact with the system from the outside. In social simulation SE practices, however, the actors are part of the system, as shown in Figure 5.4 with the examples of the Traveller agent and the Policymaker.

(a) Traveller Agent's Use Cases

A traveller can perform a list of actions while making a decision to choose a travel mode. Each of the actions is represented by an oval shape connected to the Traveller *agent* in the diagram. The Traveller agent can *evaluate* the available travel modes based on their needs and *choose a strategy* that leads to a satisfying choice among the alternatives. The travellers' selection strategies include: *observing close peer* (other travellers who are using the same travel mode), which extends to *imitating* successful peer; make an *inquiry* from others; *consider own previous option* and *consider all other options* (i.e., advertisement, promotion etc.). Travellers can also *decide* on the alternative mode to *choose* after a successful strategic decision.

(b) Policymaker Agent's Use Cases

The policymaker agent can perform actions such as *formulate policy, develop strategy, and provide interventions* which may include public enlightenment, promotions, advertisement etc.

5.3.2.2 Model Structure

Figure 5.5 is the class diagram that represents the general structure of the MOSH methodology's elements.

- The *Sociotechnical System class* has the composition of the *Agent class* that represents a list of different categories of traveller agents (e.g., cyclist, public transport user, etc.); the *Policymaker class* represents the policymaker that develops and applies interventions; and the *Opportunity class* represents different travel modes within the environment (e.g., Bicycle, Public transport).

- The *Opportunity class* is an abstract class that contains the *Opportunity Attribute class*. It has been made abstract to enable different travel modes to be created. The *Opportunity Attribute class* is needed in the *Opportunity class* to create the list of travel mode attributes relevant to the problem. The *Opportunity Attribute class* has two properties: *name* and *value.* The *name* is a space holder that allows the modeller to supply a name for the travel mode's attributes, and the *value* holds the corresponding value (the agent's perception measure) for the named attributes.

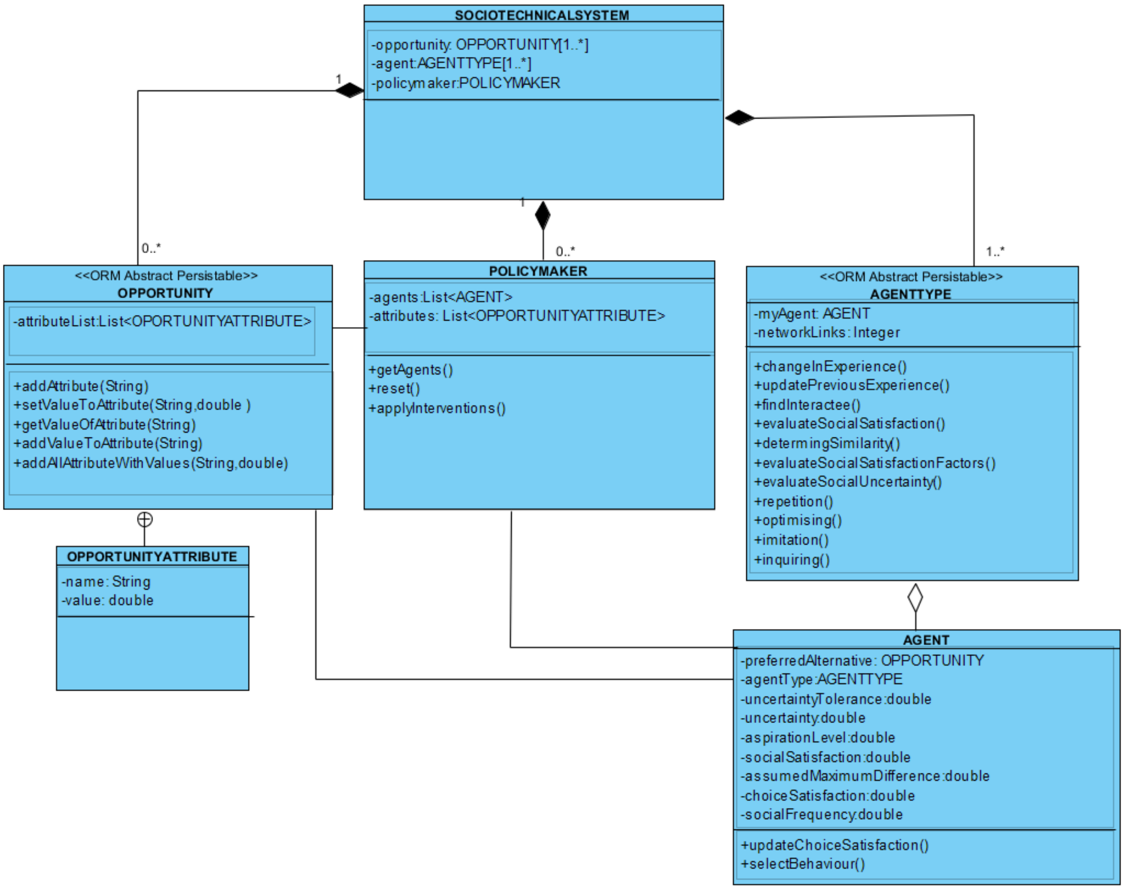

Figure 5.5: Agent-Object-Environment Class diagram

- The *Policymaker class* properties include the list of *agents* and the *travel mode's attributes*. The policymaker can perform operations such as: get the list of agents; apply interventions; and reset to normal operations without intervention.
- The *AgentType class* represents the typical Traveller Class with all the operations, interactions and behaviour of a typical traveller.
- *The Agent Class* is a specific traveller agent such as cyclists, pedestrians, train users, etc. with varying attributes that can be found in a heterogeneous population.

5.3.2.3 Agent's Behaviour

The State machine diagrams in Figures 5.6 and 5.7 are the Traveller agent's and Policymaker's discrete behaviours through finite state transitions.

(a) Traveller Agent's Mental Statechart

All traveller agents have the same basic mental states hence, the statechart diagram in Figure 5.6 represents the traveller mental states. The statechart can be extended to include other traveller's mental behaviours that suit the situation being investigated.

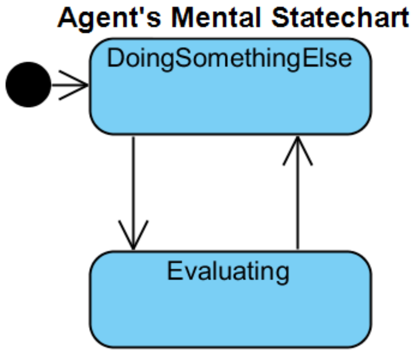

Figure 5.6: Basic Traveller Agent's mental State machine diagram

The two major mental states of a traveller agent are: *Doing something Else* and *Evaluating states*. At *Doing something else* state, the statechart shows that traveller agents are in the state where they are engaging in activities other than *evaluating* the available alternative travel modes. At the *Evaluating* state, they are evaluating their situations and needs with respect to the available travel modes.

Details of the sequence of operations within the evaluating mental states are further expressed using the activity diagram shown in Figure 5.8. It is important to state that traveller would have different physical states depending on the environment or situation. Therefore, the traveller agent's physical state will be situation-specific.

(b) Policymaker Statechart

The statechart diagram in Figure 5.7 shows the policymaker agent's physical state. The diagram indicates that policymaker can either be in the *idle state* doing nothing or be in the *active state*. While in the active state, the agent can either be in *Formulate Policy/Develop Strategy or Provide Interven*tion states.

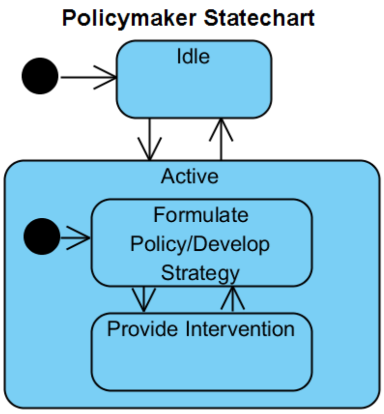

Figure 5.7: Policymaker Agent's State machine diagram

5.3.2.4 Sequence of Decision Process

To express the flow of control and sequence of the decisions within a more complex *evaluating* state shown in Figure 5.6, the activity diagram in Figure 5.8 is used.

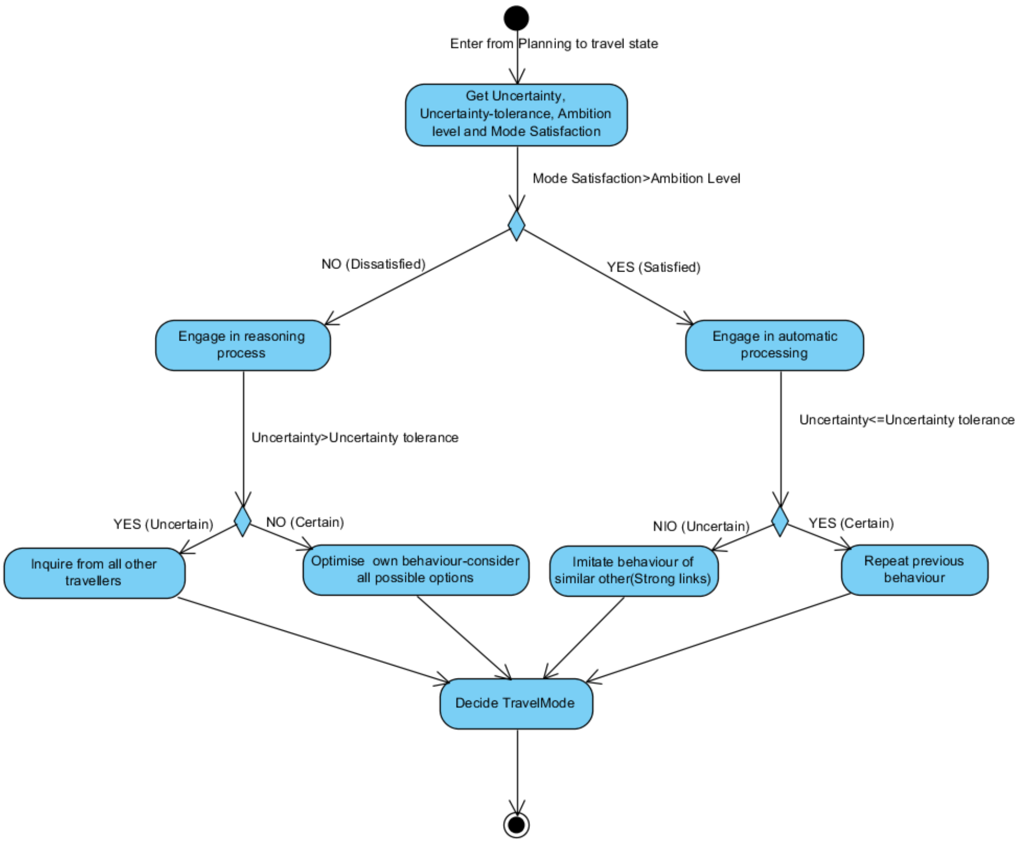

Figure 5.8: Activity diagram for the Traveller Agent's Evaluating state

The activity diagram expresses how the traveller agent evaluates their travel modes based on the four traveller agents' properties: the traveller's *previous level of satisfaction*, the *uncertainty* surrounding the decision, the level of individual *tolerance for uncertainty*, and the traveller's level of *ambition*. The details of traveller agents' evaluation process are given in Sections 5.3.2.7.

The following sections present the descriptions of the *Travel mode* and the *Traveller's* properties including the value space of the domain from which the properties are taken and how they are formalised.

5.3.2.5 Description of the Travel Mode Properties

Generally, the Travel mode *type* (e.g., bicycle) and the attributes are fixed and do not change during the simulation. The attributes of the travel modes that are of concern to the travellers are included in the simulation.

Table 5.5 contains the general properties of the *Travel mode* Class. The values assigned to each of the properties are derived from the survey dataset (Section 5.3.1).

Table 5.5: The Travel Mode's Properties Description

Characteristic	Value space	Description
Type.	Drawn from the set of travel modes to be investigated.	Type of alternative travel modes (e.g. car, cycle, bus, train, etc.).
Travel modes' attributes of concerns).	They are listed from within the boundary of the system's environment.	The primary problems area that is of concerns to the travellers.
Criteria for measuring performance (Values and priority measures).	Derived from the study's knowledge space.	The criteria to measure the achievement of the *purpose*, (a measurable output).
The functional Purpose.	Derived from participants responses.	The main and specific purposes of making use of the travel mode among other alternatives.

5.3.2.6 Description of Traveller Agent's Properties

The traveller agent's *type* is dynamic. That is, traveller agents can change their behavioural options (e.g. from public transport to car) as well as their behaviours (e.g. imitate peer, inquire from others, etc.) during the simulation. Table 5.6 shows the properties of the agent class with the elements of each column derived from the survey datasets.

Table 5.6: Traveller Agent's Properties Description

Characteristic	Value space	Description
Type	Drawn from the traveller agent's type (e.g., cyclist, pedestrians, etc.).	Category of traveller agents depending on the travel mode alternatives they use.
Needs Satisfaction	Double: data type for variable need satisfaction (i.e., default for decimal number).	The amount of positive experience with the chosen travel mode, individual taste and social interactions with others within the network.
Ambition level	Double: data type for variable traveller's ambition.	The level of satisfaction travellers aspired using the various travel mode alternatives.
Uncertainty Tolerance	Double: data type for variable uncertainty tolerance.	The level of uncertainty regarding the travel mode that a traveller accepts.
Uncertainty	Double: data type for variable uncertainty.	The negative outcome regarding expectation on the usage of the travel mode or interactions with others.
Previous Experience	Double: data type for variable previous experience.	Traveller's previous experiences on the usage of a travel mode.
Social satisfaction	Double: data type for variable social satisfaction.	Level of social agreements with other traveller agents that belong to the same social network.
Social Frequency	Double: data type for variable social frequency.	Frequency of interactions with other traveller agents.
Preferred alternative	Travel mode type: defines all alternative travel modes in the system.	The traveller's current travel mode.
Memory	Double: level of needs satisfaction, a ratio of numbers.	Information about various travel mode, other travellers in the social network and own previous experience

5.3.2.7 Formalising the Traveller Agent's Properties

The theoretical outline of the general Consumat framework described in Section 2.11.4 is used to formalise the Traveller agent's characteristics. The key components of the decision-making are the traveller's behavioural driving forces which include: the *needs* (e.g., to make a journey, etc); the available *opportunity* (e.g., private car, public transport, train, cycle, etc) to satisfy the need as well as the travellers' *abilities* (e.g., financial, physical, affective, and cognitive) to consume the opportunities. Each traveller has a *memory* to keep track of their own previous experiences and about other travellers. Travellers make use of one travel mode at a time. Depending on their *mental state* (satisfied or dissatisfied and certain or uncertain) they decide whether to engage in *information seeking strategy* to possibly increase their knowledge of other alternative travel modes in the environment. Traveller can find new information through communication with another traveller (social interactions) and through other means such as optimising or interaction with the environment (adverts, campaigns). If a traveller is repeatedly unsatisfied, the agent may decide to choose a new travel mode that better satisfies the needs.

The succeeding section formalises the Traveller's attributes, driving forces and decision-making factors.

5.3.2.8 Traveller Agents' Needs

Traveller's needs are in three categories: *existence*, *personality* and *social* needs (Section 2.11.4). Existence refers to having the continuous means of having access to available travel modes. Personality reflects traveller's style and taste (e.g., ambition, status). The social need is the traveller's need of having interaction with others, belonging to a group and having social status within its network. Each available travel mode is defined by its attributes, and how well it supports the traveller's *needs*. Travellers' *needs* are evaluated based on the levels of satisfaction and uncertainties.

<u>Level of satisfaction:</u> The level of needs satisfaction of traveller a on need d is expressed as:

$$LevelOfNeedsSatisfaction_{a,d} = \frac{\sum_{i=1}^{n}(O_x)}{n} \qquad \textit{Equation 5.2}$$

Where:

$\sum_{i=1}^{n}(\mathrm{O_x})/n$ is the mean of satisfaction responses to all attributes x of travel mode O that support the needs.

<u>Uncertainty</u>: the *uncertainty* occurs when there is variability in travellers' expectations. For instance, when there is a change in the outcome of behaviour other than what is expected.

$$LevelOfNeedsSatisfcation_t - LevelOfNeedsSatisfaction_{t-1} < 0 \qquad \textit{Equation 5.3}$$

Where:

$LevelOfNeedsSatisfaction_{\mathrm{t}}$ is the traveller's *satisfaction* at time *t*; and $LevelOfNeedsSatisfaction_{\mathrm{t}-1}$ represents the traveller's *previous satisfaction* from the travel mode.

Personality need: A traveller possesses unique personalities that distinguish them from other travellers. Notable aspects of the travellers' personality are:

- the *ambition level* (whether the traveller is quickly satisfied or not). It is a threshold that determines when the traveller's mental state is content with the current alternative. Very ambitious travellers require higher satisfaction values.
- the *uncertainty tolerance* is how well a traveller can deal with failed expectations. It is also a threshold for traveller's uncertainty regarding the current choice of opportunity.

Travellers' unique characteristics make them value one needs more than another. This affects how they respond to uncertainty and unsatisfying situations. These attributes are the measure of the weight or importance an individual attached to the needs and the capacity to endure disappointment on the expectation concerning these needs.

The Needs Weight

The weight a traveller a attached to a need d is expressed as:

$$NeedsWeight_d = \frac{importance\_d}{\sum_i^n importance} \qquad \textit{Equation 5.4}$$

Where:

$importance\_d$ is the importance value attached to all attributes that contributed to need d; and $\sum_i^n importance$ is the summation of all values regarding the importance of all needs (i.e. the set of needs) considered for traveller agent a.

For each traveller, the summation of the weights (i.e. the set of needs weights) is evaluated to be equal to 1. For example, if traveller $'a'$needs include *safety* and *efficiency* of travel mode and the *social need*, the traveller's need weight is set as $Wt_a = 1$:

Where Wt_a=($Wt_{Safety} = 0.6, Wt_{Efficicency} = 0.3, Wt_{Social} = 0.1$).

It implies that traveller $'a'$ values a safer travel mode than an efficient travel mode. In addition, the traveller is almost practically unaffected by what other travellers in the network do, because of its low social weight.

Social Need: A traveller interacts with other travellers in its social network (Section 5.3.2.13). During each conversation, the traveller store information on its communication partner in its memory (Section 5.3.2.10). Within the social need, traveller agents use the information to optimise their perceived relation to others. Then they determine their social satisfaction and uncertainty with the current opportunity being consumed.

Social Satisfaction: a traveller's social satisfaction consists of its desires for *conformity, anti-conformity* and *superiority* over others. Conformity drives a traveller to adopt similar behaviour to those around it. Anti-conformity obtains the direct opposite, i.e. being unique and therefore performing different behaviour than others. The superiority aspect reflects the traits of being superior to other travellers in the network (Jager, 2000). The more similar two travellers are in their behaviour (e.g. travel mode usage), the greater the influence they have on each other's social satisfaction.

The evaluations of the three components of social satisfaction are expressed as follows:

For a given set of Travellers A in a social network that contains traveller a.

- The conformity satisfaction of a with its current chosen *travel mode* o, is that a looks at the proportion of travellers in A (i.e. weight $i \in A$) that have the same chosen travel mode as itself.

$$Conformity\_Satisfaction_{a,o} = \frac{\sum_{i \in A} \begin{cases} wt_i & if\ o_a = o_i \\ 0 & Otherwise \end{cases}}{\sum_{i \in A} wt_i}$$ *Equation 5.5*

- The anti-conformity satisfaction is the proportion of traveller that have different preferred travel mode as travel *a*, which is simply 1 subtracted from the conformity satisfaction.

$$Anti - conformity\_Satisfaction_{a,o} = 1 - Conformity\_Satisfaction_{a,o}$$ *Equation 5.6*

- The superiority satisfaction is given by the proportion of travellers in the set A(i.e. weight $i \in A$) that have better needs satisfaction of their chosen travel mode O than a traveller a has with its own chosen alternative O.

$$Superiority\_Satisfaction_a = \frac{1}{\sum_{i \in A} wt_i} \sum_{i \in T} \begin{cases} wt_i & if\ LevelOfNeedsSatisfaction_a > LevelOfNeedsSatisfcation_i \\ 0 & Otherwise \end{cases}$$ *Equation 5.7*

Where LevelOfNeedsSatisfaction is a traveller's personal views on existence needs that are not influenced by social interactions.

Social Uncertainty: travellers' social uncertainty is related to their level of conformity or anti-conformity within the social network. When more travellers switch from traveller *a* current chosen travel mode to other alternative travel modes, then traveller *a* social uncertainty increases.

5.3.2.9 Traveller Agents' Ability

Travellers' ability determines whether they can satisfy their needs. The ability can include the financial capability, physical, cognitive and affective considerations in making use of the travel mode. Whenever a traveller's ability is low compared to the ability demanded to make a journey with the travel mode, the traveller becomes unsatisfied, therefore, seeks to increase its ability.

The following are basic abilities considered for a traveller agent:

- **Finance**
  Travellers need financial capabilities to make a journey (e.g. a public transport user requires money to obtain a valid bus pass)

- **Personal Traits: Physical**
  Travellers require physical ability to use some travel modes. For instance, bicycle and walking modes demand physical abilities.
- **Personal Traits: Cognitive**
  The use of various travel modes by a traveller requires different levels of cognition. Travellers plan their journeys based on the available travel mode and resources in the transport system's environment. Public transport users plan their journey around the public transport schedule. This might include checking the timetable, considering the time to walk to the bus stop, etc. Such considerations demand more cognitive effort than what it requires a pedestrian to make the same journey; however, for pedestrians, the physical requirement is significantly higher.
- **Personal Traits: Affective**
  Travellers' situations and the functions they can perform at these situations have emotional states. The heterogeneity in human nature explains why different travellers in the same situation possess different affective display.

5.3.2.10 Traveller's Memory

Travellers keep track of their *previous experiences* with their preferred travel modes, their knowledge of different travel modes, and the knowledge of other travellers within their networks in their memories.

- Previous Experience

The traveller's previous experience at time t is expressed as:

$$PreviouExperience_t = Satisfaction_t - Satisfaction_{t-1}$$ *Equation 5.8*

Where:

$Satisfaction_t$ is the traveller's satisfaction level at time t, and $Satisfaction_{t-1}$ is the satisfaction level at time t -1

- Knowledge of other alternative travel modes

Travellers keep track of alternative travel modes within the environment with their respective characteristics.

- Social Information

Travellers store information on all other travellers in its social network. Several kinds of information may be stored, including information on other travellers, their chosen travel modes, demographics, and level of satisfaction which are later used to perform the social comparison (Section 5.3.2.13).

5..3.2.11 Traveller's Mental Status

A traveller's mental status represents its current state, which indicates whether it perceives itself as *satisfied* or *unsatisfied* or *certain* or *uncertain*. The evaluation of a traveller's needs is combined with the needs' weights in order to update the mental state. For example, if N is the set of a traveller's *needs*, the general measures of the traveller's satisfaction with its current *travel mode* is expressed as:

$$Satisfaction = \prod_{n=1}^{n} LevelOfNeedsSatisfaction_i^{NeedsWeight_i} \qquad \text{Equation 5.9}$$

Where:

$LevelOfNeedsSatisfaction_i$ is the level of need satisfaction for the need i and $NeedsWeight_i$ is the weight that the traveller attached to need i. The $NeedsWeight$ is a Cobb-Douglas type utility weighted function that factors the total level of individuals need satisfaction.

In the equation, the measures are represented by an index that varies between 0 (fully unsatisfied) and 1 (fully satisfied). The intention is to reflect the impact of the weight on the corresponding needs.

5.3.2.12 Information Seeking Strategies

The four characteristics of the travellers that form the driving forces of its behaviour are: *ambition level*, u*ncertainty state*, *uncertainty tolerance* and *satisfaction level* (Section 2.11.4).

The choice of a travel mode for a journey is based on the dynamics of the four factors as shown below:

i Repetition:

$$Uncertainty < UncertaintyTolerance \text{ and } AmbitionLevel < ModeSatisfaction$$

A *satisfied* and *certain* traveller immediately decides whether to *repeat* its last behaviour (i.e. travel with its last used travel mode) or not without going into cognitive processing. The decision is personal and automatic, but such a traveller can still obtain new knowledge when other travellers that are *uncertain* approach it.

ii Imitation:

$$Uncertainty > UncertaintyTolerance \text{ and } AmbitionLevel \leq ModeSatisfaction$$

A traveller that engages in *imitation* feels *satisfied* but *uncertain* about its current travel mode; this removes the need for deep cognitive processing and searching for new information. A simple survey or observation of the behaviours of other travellers suffice. Individuals within a certain range of the traveller's social network (strong link) is approached for communication. The traveller only interacts with the contact if there are similarities between them. Once communication is initiated, if the initiator's satisfaction level is lower compared to the interacting traveller's satisfaction level, the initiator adopts the behaviour of other travellers.

iii Optimising:

$$Uncertainty < UncertaintyTolerance \text{ and } AmbitionLevel \geq ModeSatisfaction$$

Travellers that engaged in Optimising are *unsatisfied*, but they are *certain*, hence, they seek information without consulting their social network. Instead, they search for any new information such as interventions, adverts, promotions, campaigns from the environment. This is the only strategy that can improve travellers' satisfaction without social engagement.

iv Inquiring:

$$Uncertainty \geq UncertaintyTolerance \text{ and } AmbitionLevel \geq ModeSatisfaction$$

Similar to travellers who engage in imitation strategy, inquiring travellers feel both *uncertain* and *unsatisfied* hence, use the social network to alleviate their uncertainty. In their cognitive processing, an inquiring traveller puts more effort into learning new information by engaging in a deep and long conversation with a proportion of the population than the trivial interactions that take place within the imitation strategy.

5.3.2.13 Social Network

It is established that individuals are more likely to communicate with others that are more similar to them with a certain probability. Therefore, in a social network, the process of initialising friendship and criteria for friendship selection is important.

- Initialising Peers

In the MOSH model, the connection between a traveller and communication partner is not fixed because the need for interaction only arise when a traveller is *uncertain* about the current chosen travel mode. Those travellers that are more similar to the initiating agents are selected as their communication partners or *friends*. However, because only a subset of the population is considered, it is not guaranteed that the most similar traveller in the model is selected, but the one with a better level of needs satisfaction than the initiating traveller is selected.

- Factors of Similarity

The similarity factor is given as follows:

if F is the set of all factors that determine the similarity between two travellers, i is the set of relevant factors for the determination of similarity. Then the similarity is evaluated as:

$$Similarity = \frac{1}{||F||} \sum_{i \in F} similarity_i \qquad \textit{Equation 5.10}$$

Where:

$\sum_{i \in F} similarity_i$ is the summation of all relevant factors considered in determining the similarity among the available factors.

- Social Frequency

The frequency of social encounter (*Social frequency*) is a chance that a traveller participates in interactions with other travellers in a single time step. In the MOSH model, the frequency of interaction could be set by the modeller based on observation of the environment of the problem. However, it is possible in a time step that a traveller agent does not engage in social interaction due to the stochastic nature of the variable (i.e. the randomness in the distribution of the agent) in the social networks.

5.3.3 The Model Implementation Stage

The simulation model development process takes place at the implementation stage. The conceptual model is converted into a computer model using the MOSH methodology's libraries. The libraries are developed in Repast Simphony environment (see Section 3.4.5).

The simulation development process begins with the creation of a new project in Repast Simphony. Creating a new Repast project follows the standard Eclipse IDE new project creation wizard. A new Repast Simphony project can be made by specifying 'Repast Simphony Project' from the list while completing the eclipse wizard process. The workspace consists of functionalities including the Repast Simphony Development Libraries that assist the modeller in building Repast Simphony model.

MOSH Methodology Packages

The MOSH methodology's libraries contain packages that can be adopted and adapted at various stages of the simulation model development. The packages and their respective classes (the operations and functions) are discussed in the following sections.

5.3.3.1 The MOSH Package: ContextBuilder Class

Model Initialisation

Every modal shift model must include a *ContexBuilder* implementation which builds and returns a context., A *Context* is the core concept and object in Repast that provides a data structure for organising agents from both a modelling perspective as well as a software perspective. In other words, it is a bucket that contains the traveller agents, the policymaker, as well as the travel mode and projections. Projections specify the relationship between the agents in a given context. The Repast *ContextBuilder* interface is used to model implementations that perform context loading. The simulation model is initialised when the context is loaded. The process may be thought of as the model's '*main*' function in Java applications that assembles the model components.

In the MOSH methodology, the modellers can implement their own Context by extending the Repast *DefaultContext* class which is the recommended practice since the default implementation contains all of the working implementations for the *Context* interface. A sample Context Builder class named 'MoshProjectContextBuilder.Java' that resides in root package *'moshproject'* is adapted in our case study example.

5.3.3.2 moshproject.common package

The *common* package of the MOSH methodology libraries consists of the Utility classes that are designed to perform various house cleaning functions such as normalising a set of values to index between 0 and 1 and decomposing the decision factors components into their respective units. The classes are explained in the following:

(a) normaliseWeightValue Class

normaliseWeightValue Class takes an array of values from the travellers' perceptions regarding their travel modes and produces normalised values for respective entries.

(b) pCADeCompose Class

The *pCADecompose* class is a general template for the decomposition of travellers' decision factors into its constituent parts. For instance, the *physical*, *cognitive* and *affective* considerations in a traveller's decision can be broken into the proportion of each aspect considered in decision-making.

The pCADecompose Class works by taking in the traveller's satisfaction value and then:

- unbundles the value to its constituent parts, specifies the strength and the level of contributions of each of the constituents. The intention is to enhance decision support by providing better information for policy formulation and the development of strategies for the improvement of the affected areas.
- generates the number of times or the frequency that a decision factor is considered during the decision-making process. This will also provide information about how important are the decision factors to the decision-maker.

5.3.3.3 Moshproject.fuzzycollections package

The *fuzzycollections* package consists of all classes related to fuzzy system operations. There are two categories of operations in the *fuzzycollections* package:

i The first operation involves the travellers' Affective Display Generation Class designed to generate affective perception from the survey data. The Class has the following operations that must be executed in order to produce travellers' affective component of the decision:
   - AffectiveComponents Class: allows the modeller to define the attributes that form the affective factors (e.g. the importance and satisfaction of a concept).
   - AffectiveExcelReader Class: create a new Excel sheet and read the content of a specified file that contains the dataset related to the affective components.
   - AffectiveGenerator Class: The engine that produces the traveller's emotional value from the datasets recorded in the Excel sheet.

ii The second operation caters for problems that may require a fuzzy decision method to determine the traveller's satisfaction level (example in Chapter 6). The classes and operations are described below:

- DecisionComponents Class: allows modellers to define the factors considered by a traveller in the decision process. For instance, *ease of accessing the information* on a travel mode or *ease of getting On and Off* a mode.

- DecisionGenerator Class: The engine that produces the traveller's levels of need satisfaction value.

5.3.3.4 moshproject.agents.agent package

The *agent* package contains the *AgentType* class that represents a typical Traveller agent which has behaviour and that can engage in all operations.

The description of the operations in the AgentType class is as follows:

- *evaluateChangeInExperience:* The method evaluates the change in traveller's experience using equation 5.8.
- *updatePreviousExperience:* After evaluating its experience, the traveller updates its memory as discussed in Section 5.3.2.10.
- Behaviour/Information seeking strategies: In each time step, a traveller must engage in one of the behaviours or information-seeking strategies as discussed in Section 5.3.2.12.
- *socialNetworking:* A traveller agent uses the following methods to achieve the objective of interacting with other travellers:

  i Findinteractee: the method gathers a list of *friends* i.e., other travellers in a traveller '*a*' social network.

  ii EvaluateSocialSatisfaction: this method takes the list of selected *friends* as input parameter and determines the traveller's social satisfaction with respect to the social environment (i.e. conformist, anti-conformist, and superiority)

  iii *determineSimilarity*: the method takes a selected *friend* as input and determines the similarity with the traveller '*a*' based on specified criteria (e.g., occupation, disability, age) set by the modeller (Section 5.3.2.13).

  iv *evaluateSoicalSatisfactionFactors*: The method accepts the list of selected *friends* in the traveller '*a*' social network and determines '*a*' social weight as discussed in (Section 5.3.2.13)

  v EvaluteSocialUncertainty: social uncertainty is determined using the social satisfaction levels of conformity or anti-conformity (Section 5.3.2.8).

5.3.3.5 moshproject.agents.opportunity package

Any implementation of the Opportunity class is automatically applied to all objects of Class. The following are the methods implemented in the class:

- addAttribute: used to add new attributes of the travel mode (e.g. ease of accessing travel information).
- setValueToAttribute: set survey data value for the respective attribute during model implementation.
- getAttribute: retrieve a particular attribute from the list of the travel mode's attributes
- getValueOfAttribute: retrieve value for a given attribute.

5.3.3.6 How to Simulate a MOSH model

In Repast Simphony there is a strict separation between models, data storage, and model visualisation. This section explains how to run a MOSH model, generate output and visualise the time series of events.

Naturally, in modal shift problems, the classes that represent each of the agents and the travel modes are created and named as a Java class (e.g., Traveller.Java for the traveller agent; Policymaker.Java for policymaker agent, and Car.Java or Train.Java for the travel modes). State machine diagrams can also be included to monitor the state of the agents (as shown in Chapter 7).

5.3.3.7 Setting up the Traveller Agent in the model

The created Traveller agent Class must have the properties that indicate its preferred travel mode and the agent-type fields in addition to other problem's specific fields. The preferred travel mode field indicates the traveller's current chosen travel mode (e.g. bicycle, public transport, private car). The agent-type field indicates the type of traveller (e.g. car user, public transport user etc.). The reason for this is to account for the type of traveller at every time steps.

- **Build the context**

In building the simulation model's Context (Section 5.3.3.1), various participating agents are introduced into the Context with projections. For instance, travellers are initialised with their unique properties including the preferred travel mode, the proportion of a category of traveller in the population etc.

- **Using the MOSH Libraries**

With the *Agent-type* property, a traveller assumes all the operations (methods) in the AgentType by default. That is, all travellers engage in all the operations defined in the AgentType Class during the model implementation.

- **Generate model output**

Two types of output can be generated in the Repast Simphony environment: the time series visualisation of the travellers' aggregate behaviour and the datasets for non-aggregate behaviour. The non-aggregate dataset requires further analysis in order to derive useful information that supports decision-making as discussed in Section 5.3.6.

5.3.4 The Model Calibration Stage

After the implementation of the model design, is the setting up of the travel mode and travellers' properties with the collected survey data. The purpose is to prepare the simulation model for experimentations as well as to ensure further validation process of the model.

5.3.5 The Model Experimentation Stage

Model experimentation follows the calibration stage in the MOSH methodology development process map. Experimentation on the calibrated simulation model is to gain a better understanding of the real-world travellers' behaviours. The modeller decides the input parameters for the simulation and designs a set of experiments based on the hypothesis or questions to answer. Different possible data inputs can be tried out to check the attainment of the study's objectives. The experimentation can be done in multiple replications (e.g. run multiple times to observe agents' behaviours); single long run; interactive experiment (e.g. apply the intervention to the model after observing the result) or comparing experiments (e.g. comparing different experiment runs). An in-depth analysis of the results helps the discussion of the lesson learnt from the experiments and make a proposal on how to address the weakness of the methodology.

5.3.6 Experimental Output Analysis

Large volume of datasets is common to ABSS simulations. The experimental output analysis stage is required to derive patterns of information from the datasets arising as the experimental output. The need for further analysis and plotting of results is to enable useful and meaningful information to be derived for decision support. The process may require the application of suitable statistical and intelligent data analytics tools such as clustering algorithms to identify new knowledge in the datasets which can assist in making informed decisions. The outcome of the analysis and interpretations process can be a validation of observed phenomenon or a new insight into solving a real-world problem etc.

5.3.7 Experimental Output Presentation and Usage

The last stage of the MOSH methodology development process is the output presentation and usage. This is an important stage where the results of the simulation project are presented to the user. The results are expected to be presented in an easy to understand and visually clear manner that is devoid of any ambiguities. The understanding of the result will provide the required support for decision-making. Several of the data analytics software are useful at this stage including 'R-software, Tableau, etc. In addition, desktop application packages including Excel and PowerPoint are helpful to present visually attracted reports of such outputs.

5.4 Reflection on the Modal Shift Methodology

The novelty of MOSH methodology emerges from its capabilities to investigate the significance of decision variables in travellers' mode selection process and its ability to generate travellers' affective display value directly from the survey data. The framework that forms part of the methodology provides a means of analysing the system environment with the dynamic travellers operating in the environment. The inclusion of the *Fuzzy Collection package* into the methodology's modelling process offers the support to identify the contributions of each decision variables to travellers' mode choice. The aforementioned features are currently not available in any of the existing frameworks reviewed.

In terms of flexibility, the design of MOSH methodology allows practices and tools from other disciplines to be incorporated at various stages, especially in the areas that have specific problem context. For example, a suitable data gathering method could be employed to gain an in-depth understanding of the problem area during the knowledge gathering process. Also, in evaluating the decision-making process, modellers have the flexibility of using different techniques suitable for the situation being modelled depending on the nature of uncertainty within the problem area and the frequency at which the decision needs to be made. For instance, the use of *utility functions* can be a suitable method to evaluate decision that does not involve observations over a period, while the *moving average* function can be suited to get the overall idea of the users' perceptions over a period of time. The use of UML notations, that is independent of the implementation software, provides the opportunity for the design to be implemented in any object-oriented programming language or simulation software. However, the use of UML in the methodology does require modellers to understand some basic UML. Specifically, an understanding of the diagrams adopted in MOSH is required.

5.5 Summary

The Modal Shift (MOSH) methodology discussed in this chapter is a step-by-step process of how stakeholders can use and collaborate to build simulation models on travellers' modal shift problems. The description of the methodology process map including all stages (and the phases within a stage) that incorporated HF and PSY knowledge into the modelling process is presented with an illustrative example. The example focuses on understanding what constitute decisions made by a set of University travellers regarding the physical, cognitive and affective travel requirements.

The chapter starts with an explanation of the need to develop the Framework into a methodology that includes processes and procedures that represent the system development lifecycle. The aspects of the process map that have general purposes and those meant for specific purposes are specified. The general-purpose aspects have been built into reusable templates so that they can later be extended to serve specific purposes as demonstrated in the two case studies (chapters six and seven). The templates include the knowledge gathering template, application of CWA in data analysis, the affective display generator template, and the agents' decision-making processes. The reflection on the components, processes, and procedure of modal shift methodology is presented.

6 Case Study 1: Stimulating Modal Shift from Motorised to Non-Motorised Travel

This chapter presents a case study that demonstrates the applicability of the MOSH framework in supporting strategy development and policy formulation to stimulate motorised travellers (e.g., private car users) to adopt a non-motorised travel mode (e.g., cycling, walking etc.). The problem to be addressed is identified in Section 6.1. The definition of the problem including the aim and objective as well as the working hypotheses is detailed in Section 6.2. Section 6.3 discusses the knowledge gathering process. The data collection process is detailed in Section 6.4. The details of the data analysis process taken in the study including the data cleaning and construction of the abstraction hierarchy are presented in Sections 6.5 and 6.6 respectively. The Model development stage that uses the framework for the conceptualisation and the design of the case study is presented in Section 6.7. Section 6.8 focuses on model implementation, verification and validation. Section 6.9 details the model calibration, including parameterisation and agent initialisation. The model experimentation and results are discussed in Section 6.10. Recommendations for policymakers based on the results of the study are presented in Section 6.11. Section 6.12 contains the reflection on the application of the MOSH framework for the case study while Section 6.13 presents the limitation of the MOSH framework to the study. Finally, the Conclusion and the chapter summary are presented in Sections 6.12 and 6.15 respectively.

6.1 Problem Identification

The challenges of continuous car dependence are not limited to traffic congestions and environmental pollutions; it includes health-related issues due to inadequate physical activities. Despite the awareness, societies around the world remain heavily car-dependent. Many short urban trips are still being undertaken with private cars. French *et al.* (2014) observed that nine out of ten short distance journeys could be made by public transport and non-motorised travel modes such as walking, cycling, skateboarding and scootering. Engaging in non-motorised travel allows people to meet the recommended level of exercise just by making everyday journeys while addressing the challenge of car dependency. However, many people who could have adopted non-motorised travels fail to do so due to a combination of reasons that include *ergonomics* and *psychological factors* (Pooley *et al.*, 2011). Despite the reasons, there is a need to encourage non-motorised travel in society to reduce the impact of private car usage on the environment. It would also ensure a healthier lifestyle which could save individuals and the government from spending on health conditions linked to physical inactivity.

To achieve this objective, effective policy formulation that involves both transport infrastructural improvement and complementary behaviour change measures are required. Consequently, within the identified problem, this chapter focuses on a specific case discussed in Section 6.2.

6.2 Problem Definition

The focus of the case study is to examine the public views within the city of Nottingham regarding the challenges associated with short distance journey (e.g., getting to the grocery store) with travel modes that demand physical efforts, with a view to improving their travel experiences.

6.2.1 The Aim and Objectives

The specific aim of this case study is to test the effectiveness of the MOSH methodology for policy formulation and strategy development in stimulating travellers' behaviours for modal shift from motorised travel to non-motorised travel on short distance journeys. The objective is to investigate how both ergonomics and psychological factors within the non-motorised travel environment impact on the travellers' decisions to travel with the modes that require more physical abilities on their short distance journeys.

6.2.2 Hypotheses for Purpose Achievement

The criteria for the achievement of the study's aim include the following working hypotheses:

- Improvements in the safety, comfort, convenience and journey-time of travellers in a non-motorised travel environment influence the decision of motorised travellers to adopt non-motorised travel on their short distance journey.
- Social interactions among travellers influence motorised travellers' behaviour toward adopting non-motorised travels for short distance journeys.

The following sections explain the processes taken in answering the hypotheses set for the study.

6.3 Knowledge Gathering

6.3.1 Initial Interviews

In order to gain some background knowledge of the current situation regarding the non-motorised transport environment in the city, initial interviews were conducted amongst regular non-motorised and motorised travellers. The contents of the questions focus on the relevant infrastructure and resources within the environment to make a non-motorised journey. Common terms to be used in the study were defined with the intention to encourage easy communication of ideas among members of the project team who might come from different backgrounds.

The participants' responses were analysed and the results of the analysis provided insight into the aspects of the system that influence travellers' decisions. Four themes: *travellers' comfort, safety, convenience and journey-time* were identified as the main source of concerns to both regular non-motorised travellers and motorised travellers. The themes are as a result of psychological factors arising from the constraints imposed by some ergonomic factors in the environment.

6.3.2 The Questionnaire Design

The questionnaire method was used in the data collection process. The questionnaire for this study (Appendix A) contains relevant items of concern to the travellers as identified during the interview. The following concepts of the non-motorised transport system were included in the investigation*: sidewalks and cycle paths and footpaths, crossing facilities and road signs, 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, and health benefit of active living*.

The three sections in the questionnaire are:

1) the *general information section* that includes the demography and other information peculiar to the travellers and their non-motorised travel modes;

2) *non-motorised transport users' perceptions section* which includes questions related to non-motorised travellers' satisfaction, reasons for being dissatisfied, and suggestions for improvements.

3) the *motorised traveller's section* collects information on the reasons for not being a non-motorised traveller on short distance journey. It also collects the suggested solutions to the current challenges of non-motorised transport systems and the likelihood of adopting non-motorised travel modes for a short journey if challenges are resolved.

The validation and reviews of the questions were made by consulting experts in Human Factors and the Transport Psychology domains, both from the University of Nottingham. Then, the questionnaire went through ethical approval.

6.4 Data Collection

There are 73 respondents to the survey questionnaire. These are comprised of 22 non-motorised travel mode respondents including one respondent that indicated the use of two non-motorised travel modes and 52 motorised travel mode respondents with the following distributions:

- The non-motorised travel mode respondents comprised 7 females and 15 males, aged between 19 and 53 years.
- The motorised travel mode respondents comprised 31 females and 21 males, aged between 21 and 62 years.

6.5 Analytic Processes

The analytic processes include the cleaning up of the collected survey data, the construction of an AH, and using machine learning to derive various stereotypes within the population.

6.5.1 Data Cleaning and Organisation

The collected survey data were prepared such that the responses that have more than one entry (e.g., Q4 is about the participants' travel mode has more than one response) are recorded appropriately by splitting into separate columns to indicate the options represented. The occurrence of missing values in the collected descriptive data is less than 5% of the sample size, and hence the missing values are replaced with the average of the available entries in the respective column.

Table 6.1 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 for their journeys that were identified during the initial interview are the provision of *safety, convenience* and *comfort* to the destination.

Table 6.1: Relationship table for Non-motorised Transport system environments

<table>
<tr><th>The aspects of the non-motorised mode investigated</th><th>The related transport system concept</th><th>Criteria for performance evaluation</th></tr>
<tr><td rowspan="6">(A) Sidewalk ways/Cycle lanes /Footpaths etc.

(B) Route availability and obstruction-free routes.

(C) Crossings and road signs at Junctions.

(D) The attitude of other road users.

(E) Capabilities for luggage carrier.

(F) Shower and other facilities at the destination.

(G) Journey time consideration.</td><td>Route provision
(A) and (B)</td><td rowspan="3">Safety
Contributing factors:
-route provision.
-protection and measure of safety.
-traffic controls.</td></tr>
<tr><td>Protection and measure for safety
(A), (B), (C), and (D)</td></tr>
<tr><td>Traffic control regulations
(C) and (D)</td></tr>
<tr><td>Luggage Carrier provision
(E)</td><td>Conveniences
Contributing factors:
-route provision.
-traffic controls.
-luggage carrier.</td></tr>
<tr><td>Comfort facilities provision
(F)</td><td>Comfort
Contributing factor:
-comfort facilities provision.</td></tr>
<tr><td>Travel time consideration
(G)</td><td>Journey time consideration
Contributing factors:
-travel time considerations.
-route provision.
-traffic control regulations.</td></tr>
</table>

The first column contains the aspect of the travel mode on which survey data are sought from the travellers. The second column contains the relevant transport mode concepts that have been identified as the source of concerns to travellers in the initial interviews conducted. The third column lists the criteria for measuring how well the non-motorised travel mode satisfies the needs of the travellers on one or more of the items in column 2.

To illustrate the relationships that exist among the elements of Table 6.1, the seven items in column 1 are labelled alphabets A to F. In column 2, relevant letters from column 1 are listed under the corresponding transport concepts that they are related; 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. The relationship table assists the construction of the study's AH, presented in the following section.

6.5.2 The Construction of the Study's Abstraction Hierarchy

Figure 6.1 shows the AH that presents the links amongst the components of the non-motorised transport environment. It is constructed following the *"how-what-why"* triads (Sections 2.11.1). The description and purpose serve by each level of the figure are explained as follows:

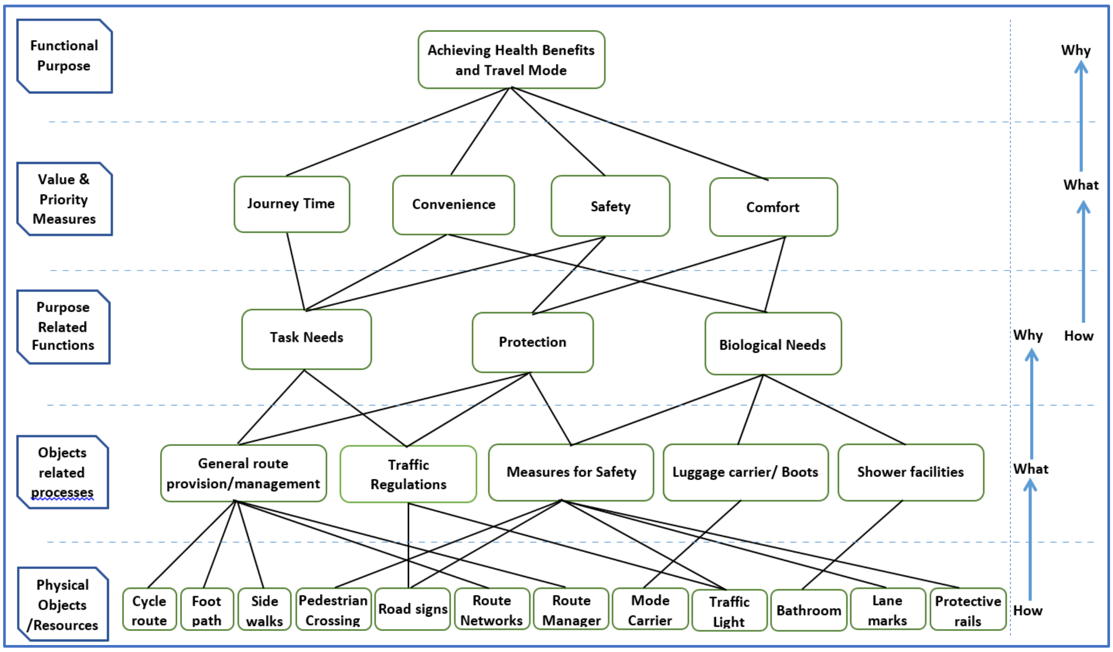

Figure 6.1: The Non-motorised Transport System's Abstraction Hierarchy

Physical Objects/resource
The physical objects level is populated with the transport system's objects and resources that are necessary to achieve non-motorised travel within the city environment.

Object-related processes
The processes involved in using the transport system resources include *traffic regulations* and the processes for *general route provisions and management*. These processes are out of the users' direct control to some degree. For example, travellers do not have control over the traffic regulation process or route maintenance.

Purpose-related functions
The purpose-related function in the AH includes catering for the travellers' *task needs*, *biological needs,* and *protections*. For instance, the purpose of a traveller needs for showering at the destination is to satisfy the *biological needs*, while a secured cycle shed caters for the travel modes' *protection*.

Values and priority measures

The identified themes that serve as the criteria with which the travellers measure the performance of the non-motorised travel mode are the *journey time, convenience, safety* and *comfort.* The *journey time* measures the concepts that have impacts on travellers' travel time (e.g., having access to direct cycle routes or footpaths). The *convenience* measures the facilities that make travellers' tasks easier and achievable. The *safety* measures how safe the travel mode is in terms of occurrence of incidences. Lastly, *comfort* metrics measures how well attributes such as shower facilities support travellers' biological needs.

Functional Purpose

The needs of a traveller on a non-motorised travel mode have been identified to include a *safe, convenient,* and *comfortable* short distance journey that supports daily recommended healthy living. The *safety* of a non-motorised traveller involves well-maintained pedestrian footpaths and walkways, clearly marked cycle lanes, good road signs, etc. The travellers' *conveniences* include the provision of facilities that support travellers tasks such as luggage carrier. The *comfort* need of a traveller involves the availability of facilities that support travellers' biological needs such as shower, seating facilities, etc. The effectiveness of non-motorised travel modes in satisfying travellers' needs could stimulate their behavioural change from motorised travel to the use of non-motorised travel modes.

6.6 Data Analysis

The analysis of the data is in two parts: 1) analysis of descriptive data; and 2) analysis of qualitative data for both non-motorised travellers and motorised travellers.

(a) Analysis of Descriptive Data

Apart from the demographic information provided in Q1 to Q11, Q12 is about the level of satisfaction of non-motorised travellers with their respective travel modes. The values assigned for the range of responses to Q12 are: "0: very unsatisfied", "0.25: somewhat unsatisfied" "0.5: neither satisfied nor unsatisfied", "0.75: somewhat satisfied", "1: very satisfied" for all attributes considered.

For the motorised travellers, Q15 collects responses on the likelihood of adopting non-motorised travel mode on short distance if their concerns are addressed. The values assigned for the likelihood of adoption are also given as: "0: very unlikely", "0.25: somewhat unlikely" "0.5: neither likely nor unlikely", "0.75: somewhat likely", "1: very likely" for all the attributes considered. The resulting dataset from Q12 is used in the classification process discussed in the next section and the dataset from Q15 is used in the experimental set up with the output of qualitative data analysis.

Learning the Stereotype within the Non-motorised travellers' population

To identify different groups within the travellers' population that have similar perceptions of the travel mode properties, a clustering algorithm is used on the datasets in Table 6.2. The datasets include the seven aspects of non-motorised travel investigated (see column one Table 6.1).

Table 6.2: Non-motorised Travellers' response Table

A Distance reasonable for Walking	B Distance reasonable for Scooter/Skater	C Distance resasonable for Cycling	D Sidewalk Perception	E Road Crossing Perception	F Others Attitude Perception	G Routes Availability Obstruction Perception	H Shower Facilities Perception	I Journey Time Perception	J Luggage Carriage Perception
4	3	6	0.75	0.75	0.5	0.75	1	0.75	0.5
1	2	2	0.25	0.5	0.75	0.5	0.75	0.75	0.5
3	4	6	0.75	1	0.5	0.75	0.75	1	0.5
2	4	6	0.75	0.75	0.5	0.5	0.75	0.5	0.5
2	3	4	0.75	0.5	0.25	0.75	1	0.75	0.5
2	2	4	0.75	0.75	0.75	0.75	0.75	0.75	0.5
3	2	4	0.75	0.75	0.25	0.75	0.75	0.75	0.75
2	3	5	0.5	1	0.75	0.75	0.75	0.25	0.25
2	1	5	0.75	1	0.5	0.75	0.5	0.75	0.75
2	1	5	0.75	1	0.75	0.75	1	1	0.75
3	3	6	0.5	0.5	0.25	0.5	0.75	0.75	0.5
2	2	5	1	1	1	0.75	0.5	0.75	0.5
3	1	6	0.5	0.25	0	0.25	0.5	0.5	0.5
2	3	6	0.75	0.25	0.75	0.75	0.75	0.75	0.5
1	1	1	0.75	0.75	0.75	0.75	0.5	0.75	0.75
3	1	6	0.75	0.75	0	0.75	0.5	0.75	0.25
1	1	5	0.25	0.75	0.75	0.5	0.75	0.5	0.5
3	1	6	0.75	0.75	0.25	0.75	0.75	0.25	0.25
2	1	5	1	1	0.75	0.75	1	0.75	0.75
1	3	2	0.75	0.75	1	1	1	1	1
1	1	1	0.75	0.75	0.75	0.75	0.75	0.75	0.75

A hierarchical clustering algorithm was used to identify the stereotypes due to the limited number of datasets in the table. The dendrogram (tree-like diagram) in Figure 6.2 shows the result of the classification.

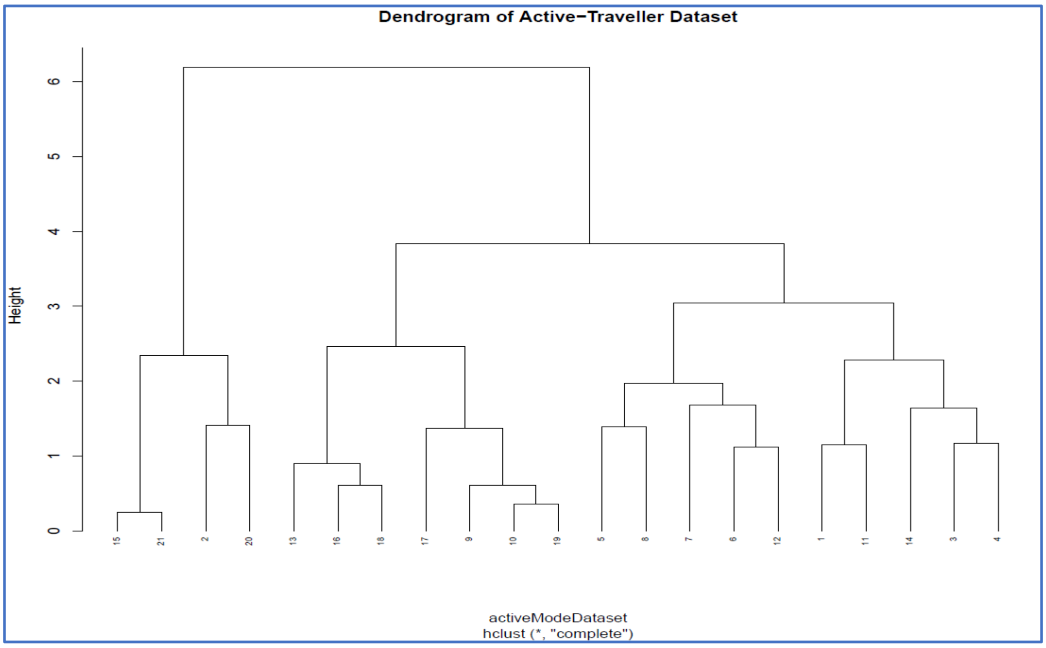

Figure 6.2: The Non-motorised Travellers' Classification Dendrogram

The agglomerative hierarchical clustering is a good algorithm for unsupervised learning. In the algorithm, each dataset point is a cluster, and clusters are repeatedly combining based on their similarity such that the entities within a cluster are as similar as possible and entities in one cluster are as dissimilar as possible from entities in another cluster. For this study, the dendrogram is viewed at height 3. Height 3 is chosen because it is at 50% of the tree height.

It is therefore, considered reasonable being the point at which datasets are exactly as similar to one another within a group and as they are as dissimilar to members of other groups. Reading from the chosen height, three different groups emerge from the population. The boxplots that represent the three resulting clusters are shown in Appendix A (A1, A2 and A3). The members of the first cluster are satisfied in all the aspects of the non-motorised travel mode except in the *other travellers' attitude* and *luggage carrier* attributes. The members of the second cluster stereotyped as group 2 are satisfied in all aspects of their non-motorised travel mode. The members of the third group show dissatisfaction in more attributes of the travel mode than the other two groups.

(b) Qualitative Analysis of the textual data

The textual analysis of the survey data for this study was developed from the participants' responses from the questionnaire's open-ended section as shown in Appendix A. The template used is shown in Table 6.3.

Table 6.3: Textual Analysis of the Travellers' responses

The aspects being investigated	Identified problems and problem's sub-category	Suggested solution space	Criteria to measure performance
Sidewalk ways and cycle lanes.	Walkways' opened edges. Non-rideable cycle routes. Poor planning, no dedicated cycle lanes, and Maintenance problem.	Make paths on both sides of the road not close to gardens; Regular maintenance; Dedicated cycle lanes and Separate walkways.	Convenience. Journey time.
Route availability and obstruction-free.	Parking on cycle and walkways; No direct or continuous links or routes; Frequent mounting and disembarking due to obstruction or constructions.	Public awareness and Good path networks.	Safety. Journey time.
Crossing and road signs at junctions.	Crossing facilities too far apart in some cases; and Inadequate road sign.	Install more crossing facilities to reduce long-distance walk before crossing; electronic stop buttons at junctions.	Safety. Convenience. Journey time.
The attitude of other road users.	Dangerous driving; Abuse; Pedestrian and drivers pulling over dangerously.	Digital warning; Cyclist lanes; Campaigns about safety; and Legislative against bad driving.	Safety
Capabilities for luggage carrier.	Reduced luggage capacity.	-	Convenience.
Shower and other facilities at the destination.	Inadequate facilities and Lack of facilities.	Make provisions for shower facilities at every working place.	Comfort.
Journey time consideration	Increase in journey time and set out earlier than usual.	-	Journey time.

Column 1 of the table contains the seven attributes of the non-motorised travel environment being investigated. Column 2 listed travellers main concerns including the subcategories. In column 3, the summaries of suggested solutions to the respective concerns are listed. Column 4 contains the general theme that is used as metrics to measure the performance of the attributes listed in column 1 of the table. However, the verbatim transcripts from the participants are used at the discussion of the simulation output later in the study.

6.6.1 Policy Formulation and Strategic Intervention Development

The formulation of policies and strategies for interventions as the techniques to address travellers' challenges are provided in the form of legislation, campaigns and building of infrastructure as follows:

(a) Sidewalk ways and Cycle lanes and Footpaths

There are general observations of poor maintenance of non-motorised transport environment facilities in the City. However, solutions to travellers' concerns include the creation of dedicated lanes for cyclists along the roads; good planning and maintenance policies to be instituted regarding the walkways, footpaths and cycle lanes. *Conveniences* in the ease of performing tasks as a result of improved facilities and the improvements in the time taken (*Journey time*) to travel to the destination due to better planning and other interventions are the metrics to measure routes related concerns.

(b) Route availability and obstruction-free routes

Travellers' concerns regarding the route availability and obstructions involve obstructions due to construction works; lack of direct links across routes in the city; and parking vehicles on the routes. This results in frequent mounting and dismounting, as well as diversions that prolong travellers' journeys. The strategy for intervention for these concerns are campaigns and public enlightenment on the need for obstruction-free routes; legislations against route obstructions and long notification and alternative routes for constructions works; and building of routes with limited interference with motorised travel modes. Travellers' s*afety* and *journey time consideration* are the metrics for measuring *route availability and obstructions* concerns*.*

(c) Crossing and road signs at junctions

The travellers' concerns regarding *road crossing* and *road signs* include the distance between road crossing facilities that prolong journey time and constitute safety risk for impatient travellers. The interventions for the concerns involve the 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-motorised travellers during bad weather such as rain, snow etc. Such interventions may promote the likelihood of motorised travellers to change to non-motorised travel modes. The metric for measuring the concerns are the travellers' *safety, convenience* and *journey time* consideration.

(d) The attitude of other road users

Dangerous driving habits, abuse, road users pulling out unexpectedly are among the concerns of travellers regarding the *attitude of other road users*. The strategies for behavioural change include dedicated lanes for non-motorised travellers, campaigns on the rights and safety of all road users as well as legislation against bad driving. More CCTV cameras are installed on the streets that primarily rely on neighbourhood watch. Travellers' *safety* is the main criterion to measure the a*ttitude of other road users* towards non-motorised travellers in the City.

(e) Capabilities for luggage carrier

One common challenge for all travellers is the limitation in non-motorised travel modes capacity to carry luggage. This challenge can be classified as 'hard constraints' (Stanton *et al.,* 2013). Interventions to such challenges are mostly through manufacturer design initiatives (e.g., the inclusion of luggage carrier 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 for 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 *conveniences* a traveller enjoys.

(f) Shower and other facilities at the destination

Shower and other facilities at the destination are part of the concerns peculiar to travellers to workplaces and education. Inadequate or complete lack of such facilities to refresh at the destination after long walking or cycling discouraged many motorised travellers 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 motorised travellers to adopt non-motorised travels. *Traveller's comfort* is the criterion to measure showering and other facilities at the destination.

(g) Journey time consideration

Generally, many non-motorised travellers showed concerns about the longer time taken to travel compared to motorised travel. Hence, the reasons for their needs to set out earlier for their journeys. Other major contributors to journey-time concerns are the *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.

6.7 Model Development

6.7.1 Conceptualisation

The model development process starts with the conceptualisation of the travellers' decision process on a short distance journey with the MOSH framework described in Chapter 4. The design captures the process involved in choosing a travel mode on a short distance journey. The purpose is to study travellers' behavioural change in mode usage when interventions to improve the non-motorised transport are provided. The motorised travel mode users are typically car users on short-distance journeys (e.g., visiting the grocery). A motorised travel mode user can choose from among cycling, walking, skateboarding and scootering after the behavioural change. For such to occur, motorised users' perceptions of the non-motorised travel modes could be influenced through: 1) interactions with other travellers who are regular non-motorised travellers; 2) through personal curiosity to improve satisfaction regarding individual concerns in a non-motorised travel mode environment.

Figure 6.3 is a process flow diagram that describes a traveller's decision process while making a short distance journey.

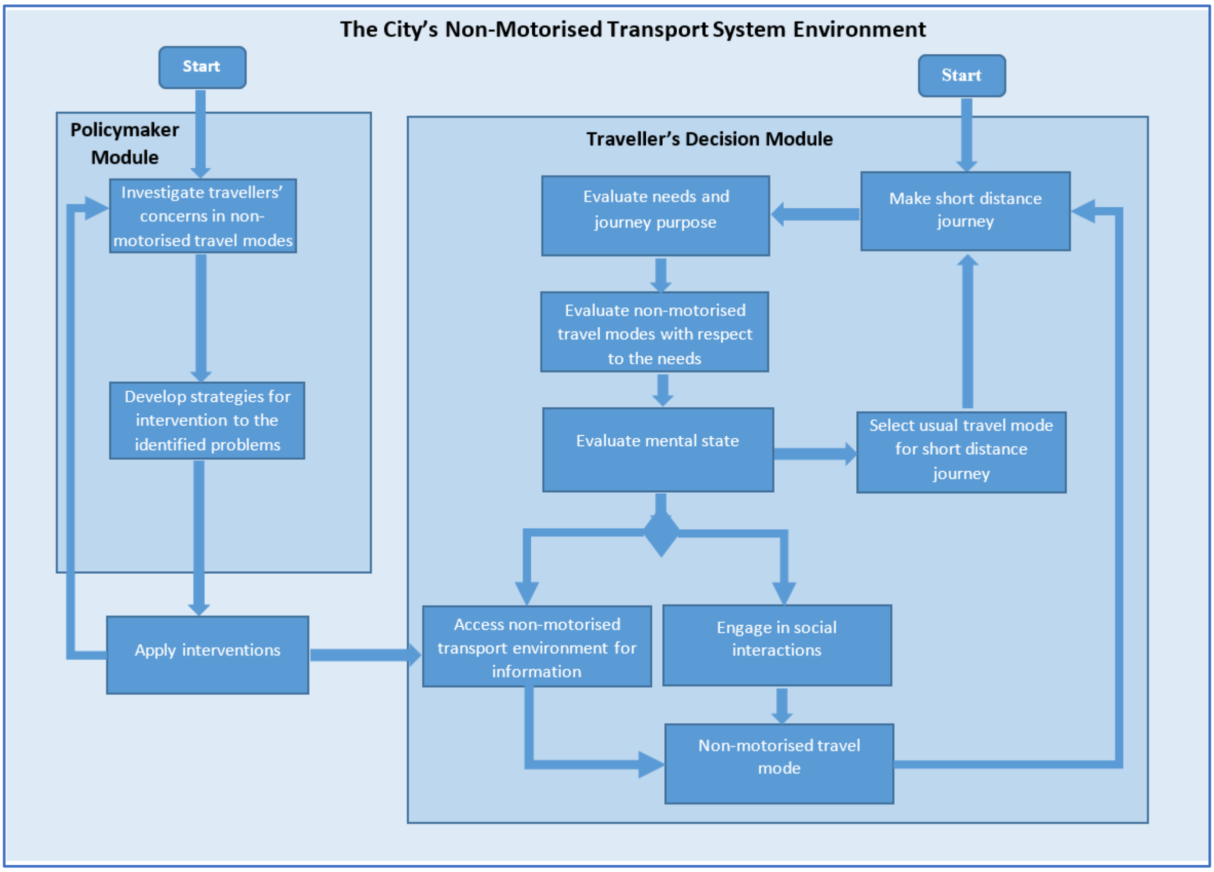

Figure 6.3: Traveller's Decision process Conceptual diagram

The policymaker module (left box in Figure 6.3) investigates why people prefer car travel on short distances that could be easily achieved with non-motorised travel means. From their findings, policymakers develop strategies and formulate policies that are applied as interventions to alleviate travellers' current concerns.

Travellers (right box in Figure 6.3) make 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 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 dissatisfied or uncertain traveller will engage in either social interactions with regular non-motorised travellers in the environment or seek information from the environment to know about the status of the non-motorised travel modes available that satisfy its needs and purposes. The process, if successful, may lead to the adoption of one of the non-motorised travel modes.

6.7.2 Use Cases

The use case diagram in Figure 6.4 is an extension and adaptation of the general use case templates provided in Section 5.3.2. The use case shows that traveller who wishes to make a short-distance journey *evaluates* the available alternative non-motorised travel modes based on their needs and *chooses a strategy* that will lead to a satisfying choice among the alternatives in the system.

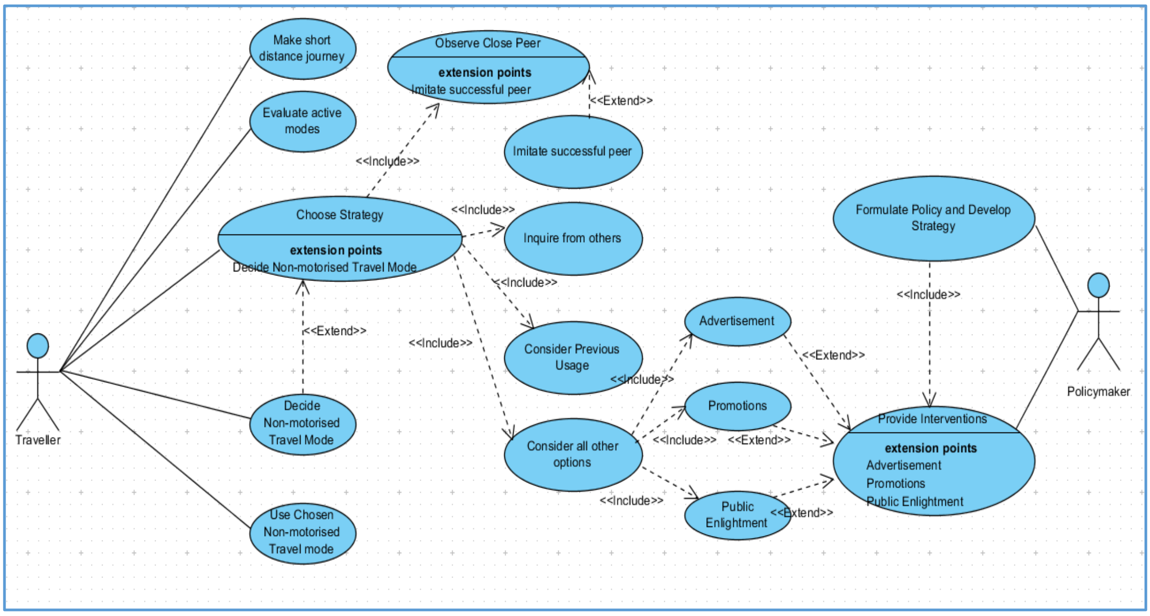

Figure 6.4: Use case diagram for Travellers on Short distance journey

Traveller's information-seeking strategies include: *observing close peers* (i.e., other travellers who are non-motorised travel mode user); which can extend to *imitating* successful peer (those who have successfully adopted a non-motorised mode in their short distance journeys) and make an *inquiry* from others. Travellers can also *consider their own previous strategies* (their previous way of making journeys) or *consider all other options* (i.e., adverts, new policies, campaigns etc.), they can also *decide* on suitable non-motorised modes to *choose* after a successful decision and make use of the chosen travel mode.

The activity of the policymaker in the use case only applies when there is a perceived unpleasant situation in the transport environment. It has the role of *developing strategies* and *formulating policies* as well as *provide interventions* to stimulate travellers' behaviours.

6.7.3 State Machine Diagram

Figure 6.5 is a state machine diagram for the physical state transitions of a motorised traveller to adopt one of the non-motorised travel modes.

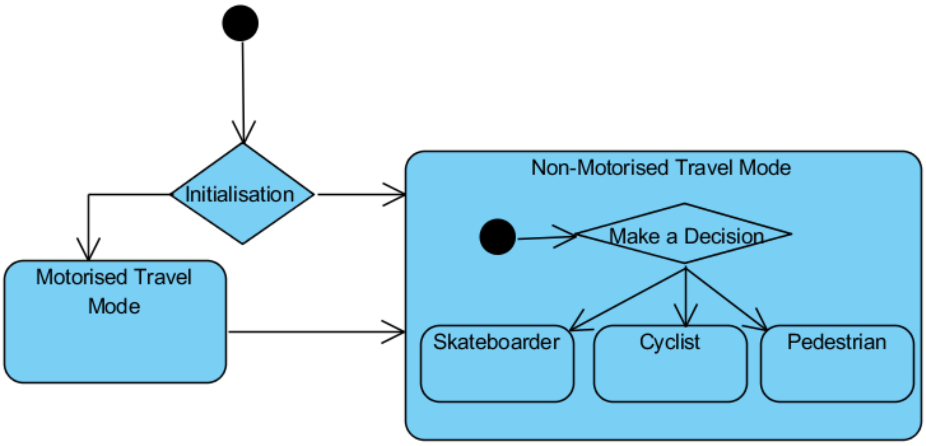

Figure 6.5: Motorised travel to Non-motorised Travel Adoption Statechart

The state machine diagram indicates that the initial population consists of both categories of travellers. A traveller can switch from motorised (car) to non-motorised travel for short-distance travel.

6.7.4 Model Structure

Relevant components of the methodology Class diagram template (Section 5.3.2) are extended to define the structure of the travel mode, the traveller and the policymaker. These are represented in Figure 6.6, Figure 6.7, and Figure 6.8 below:

(a) Figure 6.6 is the Travel mode Class extended from the Opportunity Abstract Class (Section 5.3.2) with two instances i.e., Motorised Mode and Non-motorised Mode.

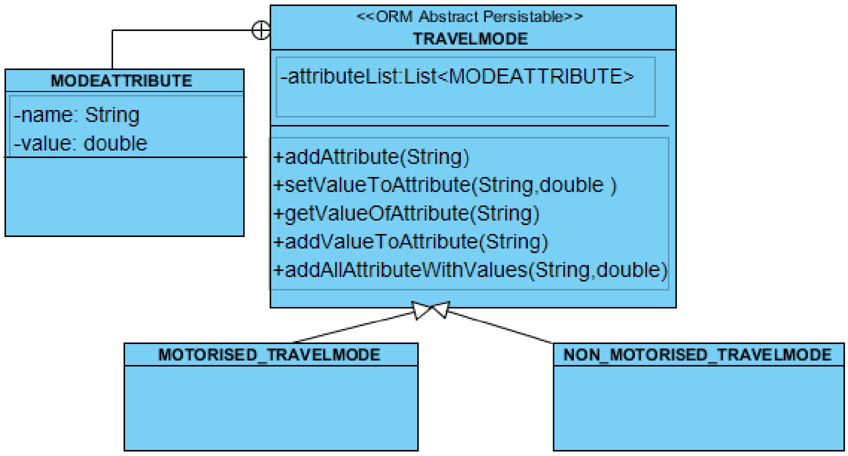

Figure 6.6: Travel mode's Class diagram

(b) Figure 6.7 shows the TravellerType Class and the Traveller class that represents a specific traveller (e.g., car users, cyclist, pedestrian, etc.) with attributes. The TravellerType and the Traveller classes are an adaptation of the AgentType Class and the Agent class in the generic template (Section 5.3.2) respectively.

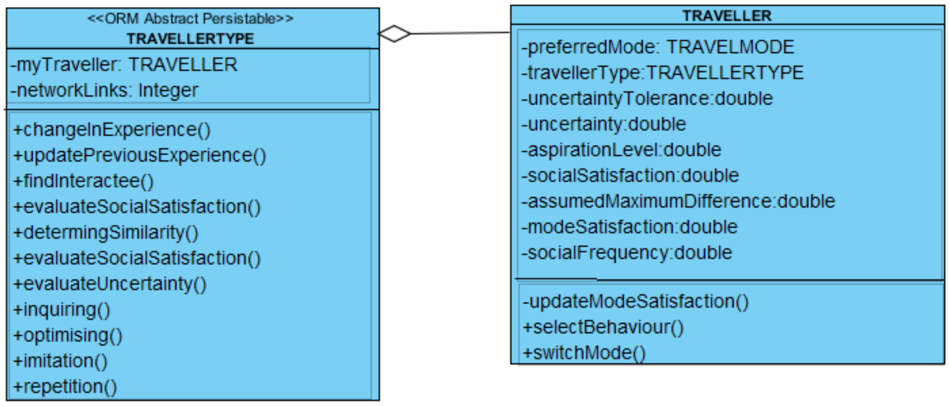

Figure 6.7: Traveller Agent's Class diagram

(c) Figure 6.8 represents the general structure of the policymaker which is adopted without any changes in the properties and operations.

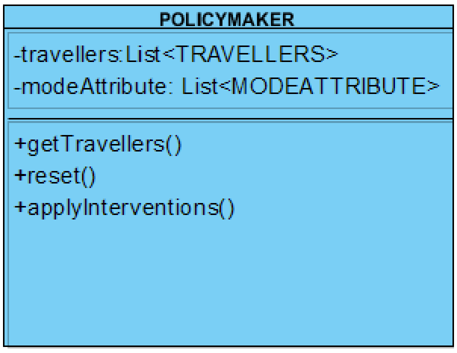

Figure 6.8: Policymaker Class diagram

In the model design, the following assumptions were made:

- Motorised travel mode users have the capabilities to make use of any of the non-motorised travel mode available.
- Non-motorised travel mode users do not shift their mode to motorised travel mode.
- All travellers have abilities to use the available non-motorised travel modes.
- Each traveller starts the simulation with a preferred travel mode.

The simplification is that travellers make use of a chosen travel mode, both, to and from their chosen destination; and the impact of disability is not considered.

6.7.5 Experimental Factors

The following specifies the experimental factors used as inputs into the simulation model.

- Policy choice based on the traveller's concerns and appropriate formulated strategies (e.g., campaigns, and legislation)
- Ratio between non-motorised and motorised travel mode users
- Demographics of the population (e.g., age; gender etc.)
- Ratio of various stereotype groups within the non-motorised population.
- Social network settings

These experimental settings allow us to create all the scenarios required for the coming experimentation.

6.7.6 Responses

The identified outputs expected to be collected from the models are:

- Time series graph to visualise the mode shift pattern from motorised travel to non-motorised (including split up into categories e.g., cyclist; skateboarder; pedestrian)
- Time series graph to visualise the influence of social interactions on the modal shift pattern (including cognitive processes)
- Time series graph to visualise on the influence of single and combined policy interventions on motorised travellers' behaviour.
- Time series graph to visualise travellers' cognitive processes in response to different policy interventions.
- Any other output that does not relate directly to hypotheses but might help to understand the processes.

The first and the third outputs help to check hypothesis 1, and the second and fourth outputs help to check hypothesis 2 (see Section 6.2.2).

6.8 Model Implementation

The MOSH methodology's libraries' templates are adapted in the model implementation with relevant aspects of the libraries used as follows:

6.8.1 Travel Mode

MotorisedMode.java and NonMotorisedMode.java classes are created as the instances of the abstract *Opportunity.java* Class. The non-motorised travel mode concepts are added to the *Opportunity.java* using the *addAttribute* method of the Class. The attributes automatically apply to the two travel mode instances created. The three alternatives of non-motorised modes that a traveller can travel with are cycle, walking, skateboarding/scootering. The motorised travel mode is private cars. The parameters discussed in Section 6.9.2 are used in the right proportion to set up the properties of the two categories of travel modes using the *setValueToAttribute* method.

6.8.2 Traveller Agent

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. The two important attributes that are required for the traveller agent set up in the simulation 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, pedestrian, etc.). In addition, there are traveller agent's decision driving factors discussed in the following section.

Travellers' Decision Driving Factors

Travellers' decision driving factors are: travellers' *ambition* regarding a need, the *needs weight*, *social weight*, *uncertainty*, and *uncertainty tolerance.*

- The *traveller's ambition* on a travel mode concept is expressed as

$$Conceptambition(i) = importance(i) \qquad \textit{Equation 6.1}$$

Where:

$Conceptambition(i)$is the importance a traveller attached to $Concept(i)$of a non-motorised travel mode.

- The *traveller's needs weight* is the importance attached to the travel mode's concept being investigated. The needs weight for all the seven concepts considered is the normalised values of a participant's responses to the *importance* questions. It is indexed between 0 and 1 and used to factor the travellers' satisfaction and uncertainty values in the simulation.

  The needs weight is expressed as

$$Conceptweight\ (i) = \frac{Conceptambition\ (i)}{\sum_1^n (Satisfaction)} \qquad \textit{Equation 6.2}$$

Where:

$Conceptweight(i)$ is the weight a traveller attached to a $Concept(i)$; $Conceptambition(i)$ is the importance a traveller attached to $Concept(i)$, and the $\sum_1^n (satisfaction)$ is the sum of all the satisfaction of concepts considered.

- *The social weight* of a traveller is evaluated from its social needs. Since it is needed when a traveller is engaging in social interactions, the weight for each of the three social aspects (i.e., conformity, anti-conformity, and superiority) is evaluated and initialized at this point in the simulation by calling the '*socialSatisfaction*' method (Section 5.3.2.8) of the MOSH methodology. The social evaluation is based on the travellers' similarities. The similarities are evaluated based on the *distance range covered* using the '*determineSimilarity'* method (Section 5.3.2.13).

- A traveller's *satisfaction on all concepts* is derived from traveller's satisfaction perceptions of the seven concepts of the non-motorised travel modes and their associated weight following the Cobb-Douglas utility functions derivatives as shown in Equation 6.3.

$$TravellerSatisfaction = \prod_{n=1}^{n} Conceptsatisfaction_i^{Conceptweight_i} \qquad \textit{Equation 6.3}$$

Where:

$TravellerSatisfaction$ is the traveller's level of satisfaction regarding its chosen non-motorised travel mode; $Conceptsatisfaction(i)$ is the traveller's level of satisfaction on travel mode, and the $Conceptweight(i)$ is the associated weighted function for $Concept(i)$.

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

- *Uncertainty* used in this study is the total uncertainties of traveller's decisions arising from previous mode usage experiences. This is given as:

$$Uncertainty_t = Satisfaction_t < Satisfaction_{t-1} \qquad \textit{Equation 6.4}$$

Where:

$Uncertainty_t$ *is* the traveller's level of uncertainty at t, $Satisfaction_t$ is the traveller's level of needs satisfaction on all concept at time t, and $Satisafction_{t-1}$ is the traveller's level of needs satisfaction at time t -1.

- *Traveller's uncertainty tolerance* values could not be initialized using the survey data, hence, a Gaussian random sample was drawn for each of the travellers at the moment of initialization. The effects of the decision are observed on the model's behaviour by varying the random sample value.

All the parameters stated above determine the traveller's mental state and information-seeking strategies.

6.8.3 Policymaker Agent

The *policymaker* agent in the simulation provides interventions to the system.

6.8.4 Build the Simulation Context

To build the Context for this project, the MoshProjectContextBuilder (Section 5.3.3.1) is adapted to contains the *traveller* agent, the *policymaker* agent and the projections.

6.8.5 Model Validation and Verification

The credibility of the model was ensured by using some of the techniques suggested by Law (2008). Firstly, it is ensured that the assumption document verified with some members that participated in the focus group meetings are valid; the model is programmed correctly, and the algorithms have been implemented appropriately. Secondly, experts in Human Factors transport research and agent-based modelling were consulted to validate the model so as to ensure that it represents the real world with sufficient accuracy for the purpose it was designed. Lastly, the descriptive data from the travellers' survey responses are compared with the simulation's base scenario (results validation).

6.9 Model calibration

The calibration, parameterisation and initialisation of the agents in the simulation model relies on the empirical data from both the motorised and non-motorised travellers' perceptions in the city of Nottingham. The next section gives an overview of the parameters used in the simulation.

6.9.1 Traveller Agents Parameterisation and Initialisation

This section describes the link between the data from the questionnaire (Appendix A) and the traveller agents' parameters. The model's value space is indexed between 0 and 1 in all situation in the simulation.

Demographical information

Each agent has a gender, an age, and travel mode on a short distance, average distance considered feasible with non-motorised travel, frequency of non-motorised travel usage, and preferred non-motorised travel mode on a short distance. The demographics information come from Q1 to Q11. The Q1 and Q2 provide information about the gender and age of the travellers. The information on gender was taken without adjustment, while the age was normalised so that it fits into the value space for the simulation. Questions Q8 and Q9 are on the average feasible distance for *walking* and *skateboarding (Scootering)*, while Q10 is on average feasible distance for *cycling*. The knowledge used in ranging the distance comes from the initial interviews granted by different categories of travellers. The participants' responses to Q8 and Q9 are converted to values ranging from "1: between 0-1 mile", "2: between 0-2 miles", "3: between 0-3 miles", "4: between 3 and 5 miles". The cycling range extends the values by adding more ranges as follows: "4: between 0-4 miles", "5: between 0-5 miles", "6: between 5 and 10 miles".

Travellers Decision Driving Factors

To formalise the importance attached to each of the seven concepts considered in this study Section 6.7.1); Q12 is used to evaluate and instantiate the personality-related parameters such as traveller's ambition and needs weight. The participants' response to each concept ranges from "0: very unsatisfied" to "1: very satisfied" for all the non-motorised travel mode's concepts.

Mode selection criteria

At the start of the simulation, each traveller is initialised with a default travel mode which comes from responses to Q4 (i.e., usual travel mode for a short distance). All traveller agents in the simulation model start by repeating their previous behaviour; that is both non-motorised and motorised travellers considered behaving the same way as they do. However, whenever there is an intervention in the transport system, a traveller may wish to explore the environment for any improvement in the services or may interact with others to improve their knowledge. Such activities are likely to improve motorised travellers' perception of the non-motorised system's environment.

The following are the major criteria used by the traveller for mode selection.

- Feasible distance for non-motorised travel: The answers to questions Q8 to Q10 provide information for the distance in miles that a traveller considers feasible for non-motorised travels. The distance ranges are: "BetweenZeroAndOne"; "BetweenZeroAndTwo"; "BetweenZeroAndThree"; "BetweenZeroAndFour"; "BetweenZeroAndFive" and "above FiveMiles". The percentage of the population of each of the travellers that belong to the distance range category is used to set up values for the attribute.

- The frequency of usage: The Q6 provides an elaborate overview of the frequency with which the non-motorised travellers used their preferred mode. It has four values that correspond to: (1) "every day"; (2) "Once or twice a week"; (3) " 3 or more times a week"; (4) " Less often". The participants' responses are copied without any adjustments to initialise the frequency of travel mode usage.

6.9.2 Travel Mode Parameterisation and Initialisation

Travel mode types

The two broad categories of travel modes considered are the motorised travel mode such as motorbike, private car, and battery-powered scooters and the non-motorised travel mode categories that include bicycle, skateboard, non-battery scooter, and walking. The travel mode is initialised following the number of users specified in Section 6.9.1.

Travel mode's concepts

Each of the travel modes has the concepts on which travellers' views are sought. The travel modes' concepts considered are: sidewalk ways/cycle lanes/footpaths, route availability and obstruction, crossing and road signs at junctions, attitude of other road users, capabilities for luggage carrier, shower and other facilities at the destination and journey time consideration. The value for each of the concepts is taken from individual travellers' perceived satisfaction and initialised with the *"setValueToAttribute"* method of the Travel Mode class.

6.9.3 Policymaker Parameterisation and Initialisation

The policymaker class runs a set of general operations that include applying interventions.

6.10 Experimentation

6.10.1 Design of Experiment and Execution

Three simulation scenarios were studied on the traveller's mode adoption pattern and cognitive processing in response to different policy interventions. The scenarios are:

i. base scenario
ii. The combined intervention scenarios that:
    a. Include luggage carrier intervention (i.e. hard constraints)
    b. Exclude luggage carrier intervention.
iii. The intervention scenarios based on the four *values and priority measures* (i.e., safety, convenience, comfort, and Journey-time).

6.10.2 Base Scenario

The default run of the simulation as parameterised with the survey data is presented in this section. This also serves as the base scenario against which the various interventions are compared.

The simulation was run 25 times over a simulation period of one and a half years, and the mean result of the runs was collected.

Figure 6.9. shows the base scenario that represents the number of travellers in various travel modes.

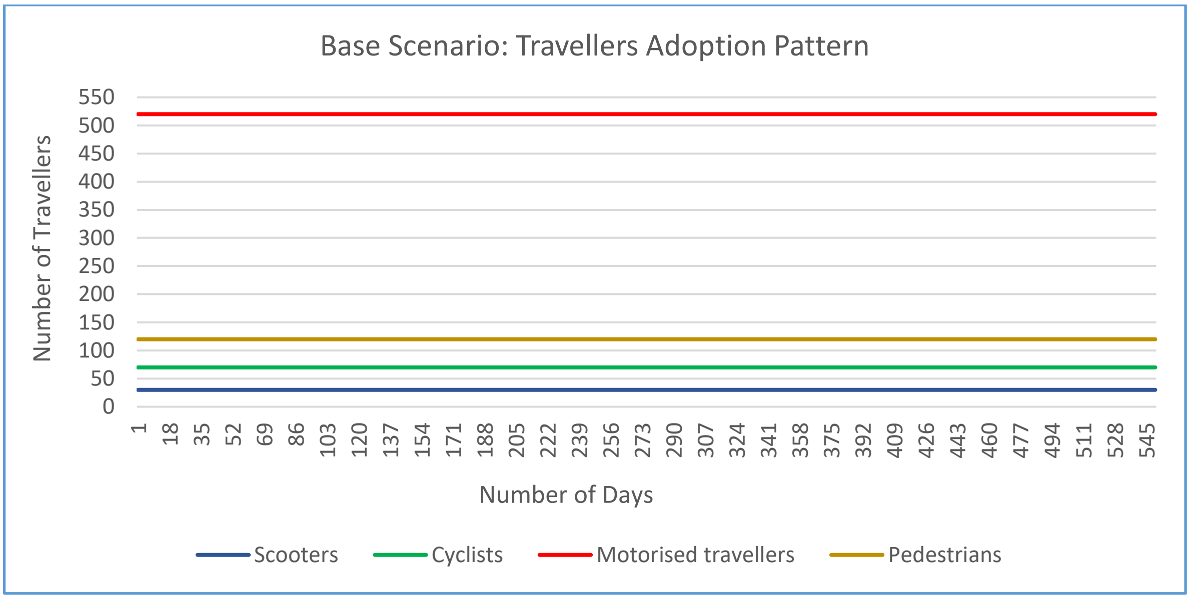

Figure 6.9: Base scenario of Travellers' Mode Adoption pattern

in the figure, the initial setup values for all categories of travellers did not change throughout the simulation time. The visual observation is expected since there are no interventions applied to stimulate the travellers' behaviours. Therefore, all travellers (i.e., motorised and non-motorised) continue with their usual travel modes.

Figure 6.10 represents the time series for the travellers' cognitive processing.

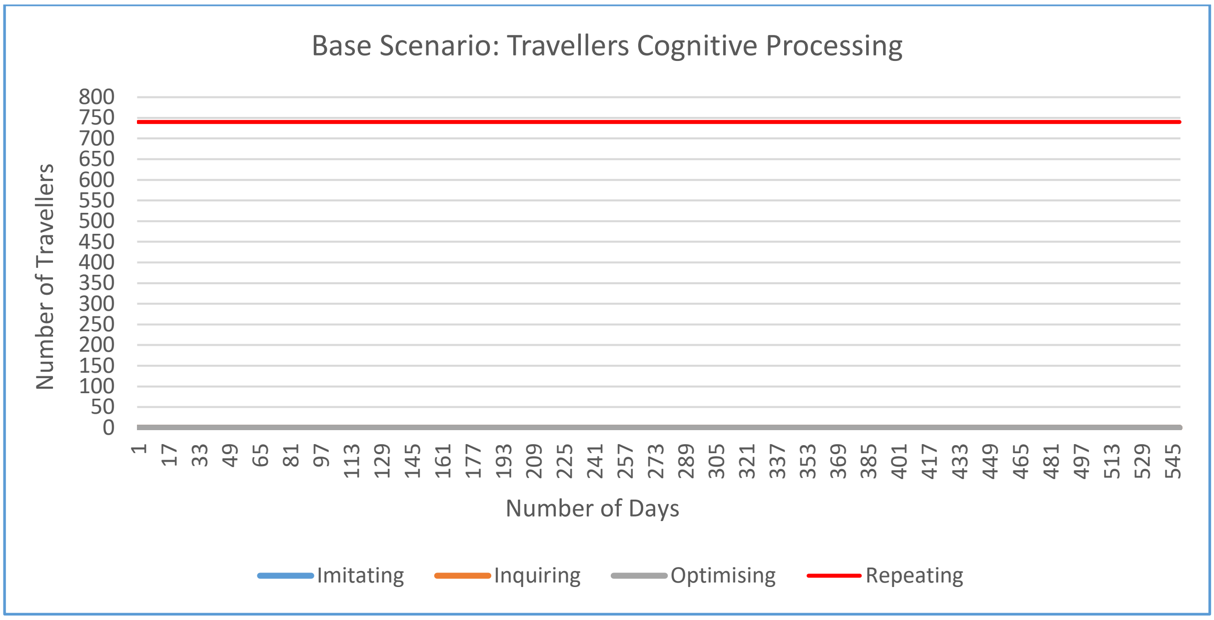

Figure 6.10: Base scenario of Travellers' Cognitive processing

Due to the absence of intervention in the base scenario, all travellers in Figure 6.10 are seen repeating their usual decision strategies throughout the simulation period.

6.10.3 Policies and Interventions

The policies and strategies for interventions provided in the experiments are selected from the discussions in Section 6.6.1. The strategies include building relevant infrastructure that supports non-motorised travel, periodic maintenance of the existing infrastructure and policy formulation.

The two sets of interventions applied are:

1) the combined interventions that include all the formulated policies and strategies,
2) the interventions that focus on *values and priority measures* (i.e., the criteria for measuring the system performance).

6.10.3.1 Combined Interventions Scenarios

The combined interventions involve:

a. all the strategies including luggage carrier which is considered 'hard constraints', and
b. all the strategies excluding the luggage carrier.

A summary of the parameters used in the combined interventions is shown in Table 6.4 below.

Table 6.4: Simulation parameters for Combined interventions involving the Two scenarios

Scenario / Travel modes' Intervened areas	Strategies with Luggage Carrier	Strategies without Luggage Carrier
- Sidewalk ways/Cycle lanes/Footpaths	✓	✓
-Route availability and obstruction-free routes	✓	✓
-Crossing and road signs at junctions	✓	✓
-The attitude of other road users	✓	✓
-Capabilities for luggage carrier	✓	-
-Shower and other facilities at the destination	✓	✓
-Journey time consideration	✓	✓

The information in the table indicates that the provision of luggage carrier as part of the interventions is only included in the first scenario but not in the second scenario. The purpose of the experiment is to investigate how the luggage carrier influences non-motorised travellers' mode's adoption differently from when it is not included.

Combined Intervention scenario with and without Luggage Carrier strategy

Figure 6.11 shows the travellers' mode adoption time series in response to interventions with and without luggage carrier. Figure 6.11(a) and 6.11(b) present the time series for the two scenarios respectively. The vertical purple line in the figures indicates the intervention point.

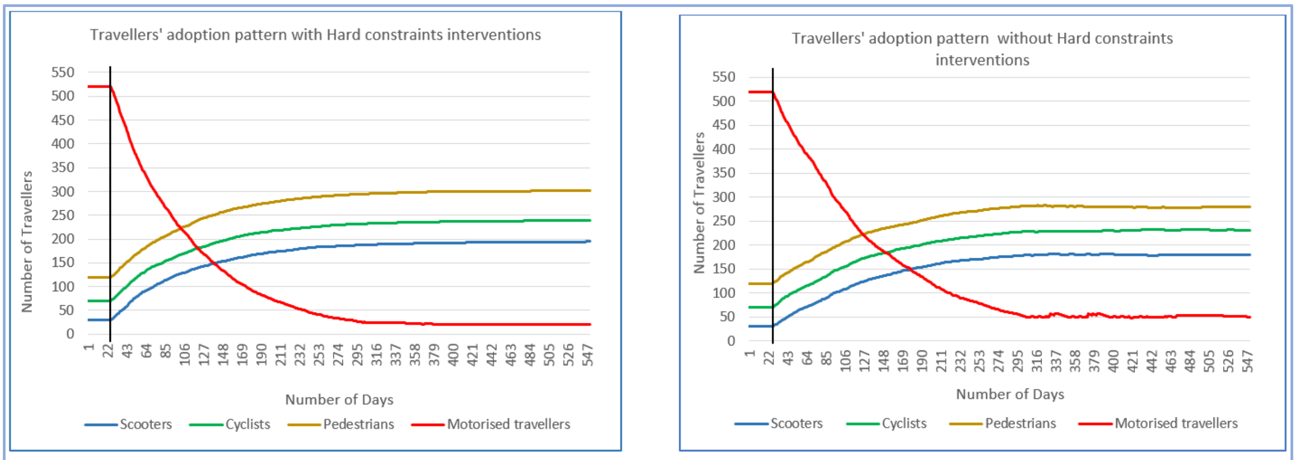

Figure a: Non-motorised travel mode Adoption pattern for all interventions

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

Figure 6.11: Motorised to Non-motorised Modes Adoption response to Combined Interventions

In Figure 6.11 (a and b), all travellers in the simulation (i.e., both motorised and non-motorised) started with their usual travel modes. This accounts for the initial steady behaviour at the beginning of the simulation until after day 25 when the intervention is applied. The travellers' adoption patterns in both scenarios show a very similar trend curve. The scenario in Figure 6.11 (a) has a quick response to the interventions at the early stage of the simulation by producing a smooth deeper curve than the scenario in Figure 6.11(b). The deep curve which transforms to a rise in various categories of non-motorised travels is as a result of early social interactions among the travellers than in Figure 6.11(b). The interactions motivated more motorised travellers to adopt non-motorised modes for their short distance travels.

Figure 6.12 presents the travellers' cognitive processing behaviours for the adoption patterns depicted in Figure 6.11 (a and b).

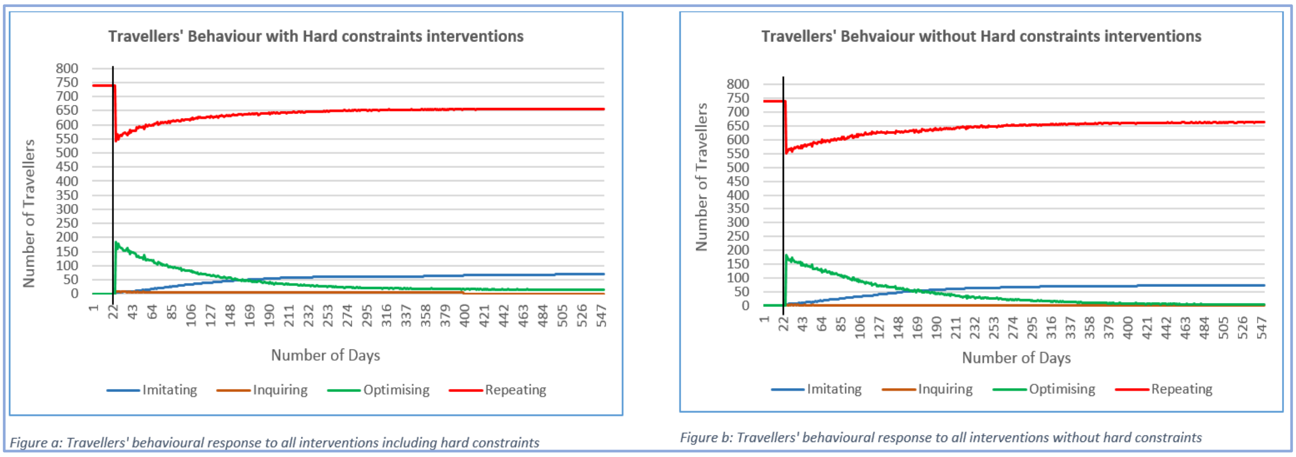

Figure 6.12: Travellers' Cognitive processing in response to Combined Interventions

The two graphs in Figure 6.12 also show a very similar trend before the intervention on day 25. The behaviours are the same after the intervention except for the variations in the time that the respective decision strategies take place and the differences in the numbers of travellers involved in interactions in the two scenarios. In Figure 6.12 (a and b), all the 740 traveller agents in the simulation are observed to be repeating their usual travel behaviour (i.e., no traveller *imitates, optimises* or *inquiries* from others).

Many travellers 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 motorised travellers get involved in *imitating* and *inquiring strategies* (i.e., social interactions) with the existing non-motorised travellers. 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.

One important insight from the scenario is that difficulties in providing 'luggage carrier' intervention on non-motorised travel modes 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 the non-motorised travel modes. Although Pooley *et al*. (2011) study used static descriptive data without considering the influence of social interactions among travellers, 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 motorised traveller that has similar journey features as a non-motorised traveller could be influenced through interactions to choose a non-motorised travel mode. it is also evident that a proportion of motorised travellers do not change behaviour. It could be that the use of non-motorised travel is practically not feasible for these set 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-motorised travellers concerns other than the 'luggage carrier'. Another insight is that interdependency among system components reveals the interplay between ergonomic factors and psychological factors. For instance, the obstruction-free routes and maintenance of walkways interventions to address journey-time consideration in Figure 6.11 (b) contributed to the resolution of the travellers' safety and convenience constraints to some extent.

6.10.3.2 Interventions on the Values and Priority Measures

The values and priority measures considered are: *comfort, journey-time consideration, safety,* and *conveniences*, and the scenarios investigated are:

- Comparing comfort and journey-time consideration interventions
- Comparing two policy interventions for travellers' concerns on safety

(a) Comfort and Journey-time Consideration Interventions

Figure 6.13 compares the comfort and journey-time consideration interventions. Figure 6.13 (a) and Figure 6.13 (b) present the time series for the travellers' travel modes adoption in response to comfort and the journey-time consideration interventions respectively.

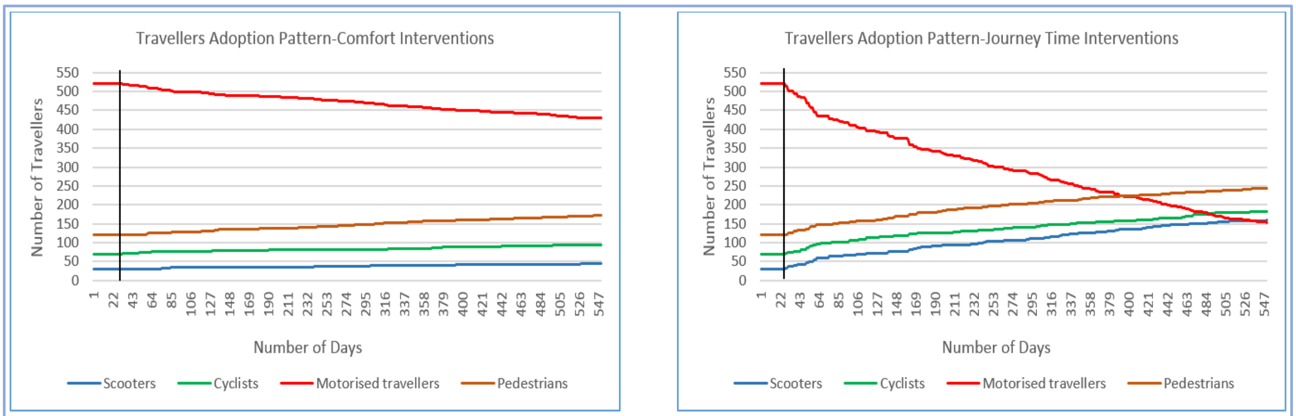

Figure a: Travellers' Non-motorised travel mode adoption pattern: Comfort interventions

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

Figure 6.13: Comfort and Journey-time Interventions Mode Adoption pattern

The only intervention provided for the comfort concern is the provision and maintenance of showering facilities at the destinations (e.g., workplace). The journey-time consideration intervention includes campaigns against routes and cycle lanes obstructions; as well as the provision of continuous link routes, road signs, crossing facilities, etc.

The initial steady-state behaviour observed at the beginning of the simulation in both graphs is due to travellers starting their journeys with their usual travel modes. In Figure 6.13 (a), there is a slow decline in the numbers of motorised travellers after the intervention on day 25 which transforms into an observable increase in the number of non-motorised travellers across various non-motorised travel modes. The reason for the slow adoption behaviour is that the intervention only provides results from 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 Figure 6.13 (b), there is a sharp decline in the numbers of motorised travellers after the intervention. The behaviour can be attributed to the importance attached to the journey-time factors by all categories of travellers.

Figure 6.14 (a) and (b) are the cognitive processing time series for the comfort and journey-time intervention scenarios respectively. The two-time series indicate that travellers engaged in all cognitive processing strategies. In Figure 6.14 (a) the number of travellers engaging in repeating and optimising strategies shows a gradual decline; while the number of imitating travellers increases as the simulation progresses. With the decline in the number of travellers repeating their previous travel mode, imitation does not transform into being satisfied and certain. The graph behaviour can be attributed to the few affected travellers who observed others on how they address their comfort concerns with success.

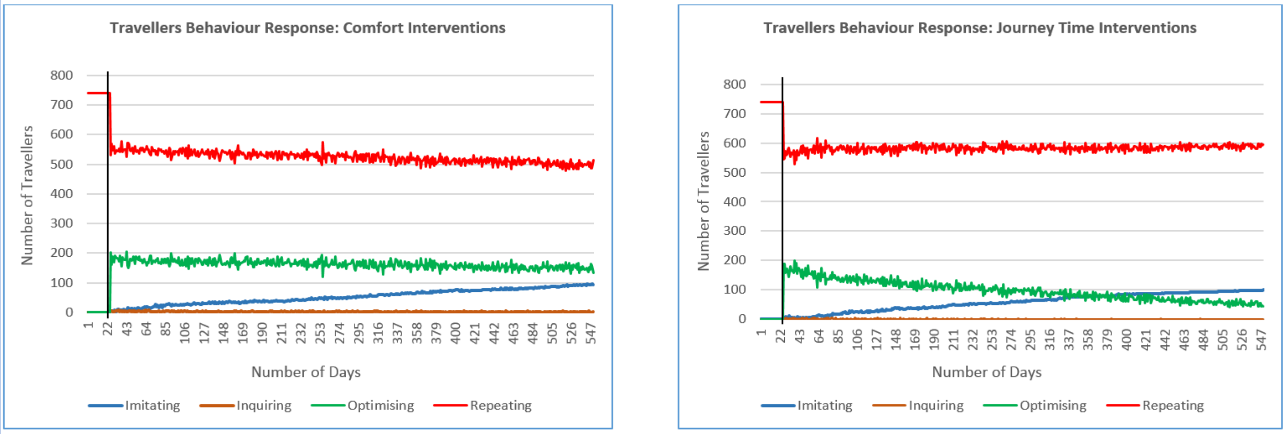

Figure a: Travellers' behavioural response comfort interventions

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

Figure 6.14: Travellers' Cognitive processing for Comfort and Journey-time Interventions

In Figure 6.14 (b) the number of travellers engaging in repeat strategy remains stable, with a gradual slow-down in the number of those observing optimising strategy; while the number of imitating travellers increases as the simulation progresses. Some of the imitations result in success, this is attributable to a non-decline in the numbers of travellers engaging in repeating strategy. The difference in the behaviours shown in the graphs (i.e., Figure 6.14 (a) and (b)) can be attributed to the proportion of travellers that have concerns about the constraints in the two scenarios and the success of the cognitive processing. The more the number of affected travellers, the more the participation in the interactions. This explains the changes in the proportion of travellers *optimising, imitating, repeating and inquiring* when compared the two figures.

In this scenario, the observable behaviour of travellers in response to interventions indicate 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.

(b) Safety Concerns' Interventions

The scenarios investigated the best time to apply or withdraw interventions and identified the best combination of policies or strategies that will be appropriate to remove a constraint. The two experiments investigated involved campaigns against dangerous driving, respect for the right of other road users as well as strategies that include the maintenance of walkways and installation of more road crossing facilities. In the first scenario, interventions were allowed to run for 90 days while the second scenario was allowed to run for 547 days (i.e., the whole length of the simulation time).

Figure 6.15 is the time series for the two safety interventions applied on day 25.

Figure 6.15(a) shows the intervention that runs for 90 days ending at day 115. The time series at the end of the simulation shows that 160 motorised travellers (i.e., 30.8%) have adopted various categories of non-motorised travel modes. In the second scenario (i.e., Figure 6.15(b)) with the intervention that runs until the end of the simulation, 350 (i.e., 67.3%) motorised travellers have adopted various categories of non-motorised travel modes at the end of the simulation.

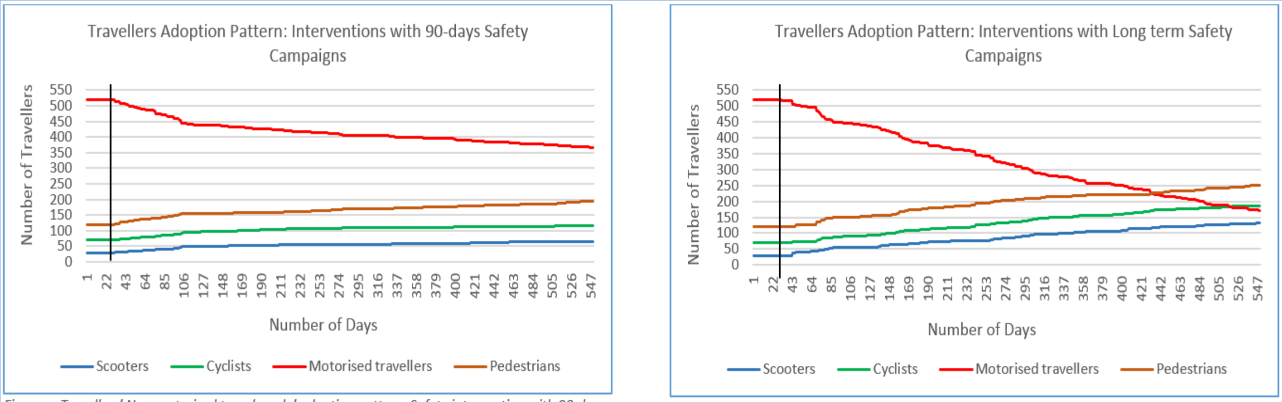

Figure a: Travellers' Non-motorised travel mode' adoption pattern: Safety intervention with 90-days campaigns

Figure b: Travellers' Non-motorised travel mode adoption pattern: Safety intervention with long-time campaigns

Figure 6.15: Safety Intervention Mode Adoption pattern

It can be observed from the two figures (i.e, Figure 6.15(a) and (b)) that the running length of the interventions impact on the travellers' mode adoption rate. That is, the longer the length of the intervention, the more the proportion of adopters.

Figure 6.16 is the travellers' cognitive processing for the adoption pattern of the two safety intervention scenarios shown in Figure 6.15(a) and (b).

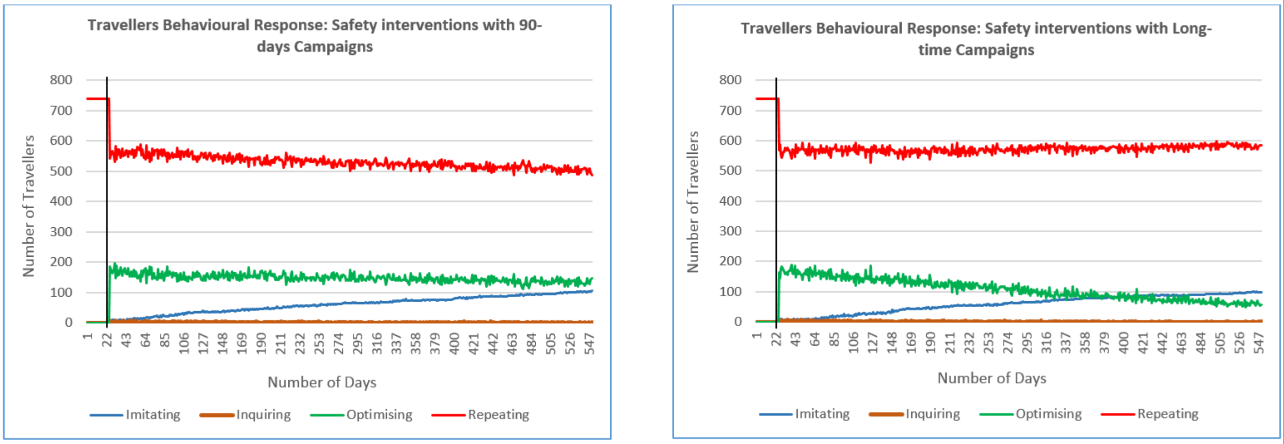

Figure a: Travellers' behavioural response to safety interventions with 90-days campaigns

Figure b: Travellers' behavioural response to Safety interventions with long-time campaigns

Figure 6.16: Travellers' Cognitive processing for Safety interventions

Figure 6.16(a) represents the travellers' cognitive processing time series in response to the safety intervention strategies with 90 days campaigns, and Figure 6.16 (b) is the time series of cognitive processing for the long-term intervention.

Different patterns of behaviours can be seen in Figure 6.16(a) and (b). Although, the same proportion of travellers started the *optimising strategy* (i.e., individual information- seeking) in the two figures. In Figure 6.16(a) the optimising travellers caused the number of travellers repeating their behaviour to reduce from the initial 740 to 550. As the simulation progresses, social interactions among travellers engaging in *imitation* and *inquiring* strategies further caused a steady decline in the number of travellers engaging in *repeating* and *optimising* strategies. In Figure 6.16 (b), a quick decline in the number of travellers engaging in *optimising* strategy after day 115 was noted and an observable rise in the number of travellers repeating their behaviour at this period. The reason is that the duration of the intervention allows more travellers to get involved in *imitating* others and inquiring from others. The duration of the intervention also allowed more travellers to be satisfied and certain about their chosen non-motorised travel.

The results from the experiment indicate that travellers are involved in the four decision strategies but fewer are engaged in *inquiring* strategy. This is expected since travellers engage in various non-motorised travel hence, a successful decision through inquiring strategy would involve a traveller to interact with another traveller having the same needs and requirements (e.g., scootering to a grocery) as the initiator of the interaction.

Although, the duration of the interventions had an observable impact on the adoption of non-motorised travel by motorised travellers, one insight from the scenario is that the continued adoption of non-motorised travel by the motorised traveller after the interventions had stopped on day 115 which implies that the desired results can be achieved with the duration of a short campaign when supported with appropriate interventions.

6.11 Recommendation for Policymaker on the use of MOSH Framework

The insights gained from the investigated scenarios in this chapter indicate that the limitations of a non-motorised travel environment regarding travellers' conveniences reduced its potentials for increasing the likelihood of its usage for everyday journeys. However, since a reasonable percentage of the non-motorised travellers in the city are cyclists, a policy that encourages the attachment of reasonably sized carrier to the modes could be helpful to alleviate the limitation. This may increase the likelihood of the motorised travellers who currently have concerns for luggage carrier to adopt cycling for their short distance journeys. Although, this measure may also increase travellers' concerns for safety due to the attachment, and due to activities of some impatient motorists. However, the safety concerns regarding the attachment can be resolved by discouraging routes obstructions in addition to campaigns against bad driving behaviours. The strategies will increase the safety confidence of travellers who might have concerns about various safety limitations in the current non-motorised environment. Besides, travellers engage in non-motorised travels for different purposes (e.g., visit, work, leisure) most of which require less need for load carrier, therefore, campaigns and enlightenment on the health benefits of making active journey could increase the adoption of non-motorised travel for other purposes.

The comfort and journey-time concerns in non-motorised travel are expressed by all travellers, although for different reasons. Comfort concerns are mostly due to the non-availability of showering facilities for travellers going to work and schools. Cycle lanes and walkways obstructions due to indiscriminate parking of vehicles are believed to prolong journey times. As a recommendation to address travellers' concerns for comfort, all workplaces and public buildings should be mandated to have in their plans the provisions for showering and refreshing facilities for non-motorised travellers. The policy can be made to operate just like the building accessibility standards for disabled people. The measure could increase the likelihood of more travellers especially those living within a walking and cycling distance to the workplaces and schools to adopt non-motorised travels.

Lastly, Policymaker should identify appropriate strategies to address a given constraint. Not all formulated policies and strategies for interventions on travellers' concerns or system's constraints might need to be applied at the same time. This is demonstrated in the intervention that involves travellers' safety (Section 6.9.3.2).

6.12 Reflection on the MOSH Framework Application

The reflections on the application of the MOSH framework in this case study highlight its strengths and weaknesses. The structural links among the system's components modelled with the AH included in the MOSH framework revealed the interdependencies among the identified constraints. This strength allows the application of a single intervention to resolve issues related to many system's constraints. For instance, obstruction-free routes and maintenance of walkways interventions to address journey-time consideration in Figure 6.11 (b) contributed to the resolution of the travellers' safety and convenience constraints to some extent. In addition, the richness of the framework to resolve psychological problems with ergonomics strategies is evident in this case. Moreover, in resource-constrained situations, the MOSH methodology's CWA supports policymakers to make informed decisions about travellers' concerns that would impact better on their behaviours. And provide insights into the combination of strategies that could produce optimum results and avoid counter-productivity.

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. However, the opportunity provided by the MOSH methodology to investigate the interactions among travellers and the influence of the interactions on their decisions is a justification of the need for the ABM paradigm in the project. Incorporating the ABM paradigm into the MOSH methodology modelling process has addressed the limitations of investigating individuals as well as the lack of interactions that can be found in the existing related studies. However, the potential of ABM in the methodology can still be further explored to understand what constitutes individual travellers' decisions rather than the aggregate cognitive processing displayed by the travellers. A step towards understanding individuals is taken in the next chapter of this thesis.

The weakness of the framework comes from the needs to learn the arts of modelling with some of the components of the methodology such as the CWA.

6.13 Conclusions on the Applicability of MOSH Framework for the Case Study

This study has demonstrated the effectiveness of MOSH methodology in supporting collaborations among experts from different domains. It also provides a modelling capability that includes the HF and PSY knowledge to investigate modal shift from motorised to non-motorised travel on short-distance journeys. The following sets of working hypotheses have been examined:

- Hypothesis 1: **Improvements in non-motorised travel environment on travellers' safety, comfort, convenience, and journey-time influence their decisions to adopt non-motorised travel on their short distance journey**. The results from all the travellers' responses to various interventions as presented in the experiments have adequately shown that the hypothesis can be accepted.

- Hypothesis 2: **Social interactions among travellers influence motorised travellers' behaviour toward adopting non-motorised travels on their short distance journeys.** The different engagements of travellers' cognitive processing in response to interventions have shown that social interactions among motorised and non-motorised travellers play roles in their adoption pattern hence, the hypothesis can be accepted.

Lastly, the case study took aggregate observations of travellers' behaviour at a high level of abstraction. It is therefore, demonstrated that the methodology can investigate problems at various level of details. In the next chapter, a case study that investigated the disaggregate properties of travellers is presented.

6.14 Summary of Case Study

The case study discussed in this chapter focuses on stimulating motorised travellers' behaviours to adopt non-motorised travels on their short distance journeys. In the case study, steps in the MOSH framework/methodology process map (Chapters 4 and 5) were followed to conduct an investigative process. Common terms in the problem area from the perspective of HF and PSY were defined to describe the features of a non-motorised travel environment. This also encourages easy communication of ideas as well as easy adoption of reusable standard design technique provided in the methodology to support collaborations among experts from the two major disciplines.

Seven system's constraints were identified from the knowledge gathering process as the areas of concerns to both categories of travellers. The concerns are organised into four themes which include travellers' *safety, comfort, convenience* and *journey-time consideration* that serve as the criteria to measure travellers' responses to interventions and on which policies and strategies for interventions were formulated.

Experiments were conducted to investigate how interventions impact on motorised travellers' behaviours to adopt non-motorised travel. The outcomes show that all factors of concerns to travellers have varying degrees of impact on their decisions to adopt non-motorised travel. A significant impact can be made in stimulating travellers' behaviour when appropriate interventions are provided at the right time. Recommendations are made based on the insight gained from the experimentation stage. The conclusion is that the two working hypotheses for the case study can be accepted.

Lastly, reflection on the strength and weakness of the MOSH framework/methodology following its performance in modelling the case study is provided.

7 Case Study 2: Understanding Individual Responses to Decision Factors

The case study presented in this chapter investigates the impact of travel requirements which include physical, cognitive and affective considerations on travellers' travel mode decisions. The general problem area is identified in Section 7.1. The specific problem to address in the case study is defined in Section 7.3. Section 7.3 presents the procedures for knowledge gathering and the data collection process is detailed in Section 7.4. The construction of abstraction hierarchy with physical, cognitive and affective indication and the analysis of the collected data are detailed in Section 7.5 and Section 7.6 respectively. Section 7.7 discusses the model development stage that includes model conceptualisation and design. In Section 7.8, model implementation, verification and validation are discussed. The model calibration, parameterisation and agent initialisation are presented in Section 7.9. Model experimentation and results obtained are discussed in 7.10. Section 7.11 discusses the recommendation for policymaker on the use of MOSH methodology. Reflection on applying the MOSH methodology is presented in Section 7.12. Section 6.13 presents the limitation of the MOSH framework to the study. Finally, the Conclusion and the chapter summary are presented in Sections 6.12 and 6.15 respectively.

7.1 Problem Identification

Many factors are considered by the travellers in their decision process to choose a preferred travel mode among the available alternatives. These factors include the travel modes' quality of services; the transport system's environment as well as the travellers' abilities (e.g., physical, cognitive and emotional) to satisfy the requirements for a journey. Due to the heterogeneity in human nature, Wardman *et al.* (2001) opined that the requirements have varying impact on individuals. Certain considerations among the travel requirements are paramount to individual travellers in their decision making. To a traveller, it could be the physical ability for the journey that is paramount, to another, it could be the cognitive demand of the journey. These considerations influence the motives for mode usage (Steg, 2005).

Investigations into the impact of these requirements have remained implicit due to limitations in the capability of the modelling methodology used (Mann & Abraham, 2006; Steg *et al.*, 2001; Steg, 2005) as well as fuzziness in the boundaries of the factors that form the decision which makes it difficult to distinctly identify which factor contributed what. The understanding of these factors and their impact could assist stakeholders in proffering appropriate interventions to stimulate travellers' behaviours. Consequently, this chapter focused on the identified problem area.

7.2 Problem Definition

The travel experiences of a set of travellers to a university on their abilities to make use of alternative travel modes are examined in this case study. The purpose is to understand what constitute the decisions made by individual travellers among the main travel requirements (i.e., physical, cognitive, and affective) considerations. Also, what level of considerations of these requirements are involved in the traveller's decision to satisfy their needs. Individuals abilities to use a travel mode is influenced by *ergonomics factors* including the constraints within the transport system's environment as well as *psychological factors* such as concerns for safety which impact on their physical, cognitive and emotional views. The travellers in this case study are academics, full-time students, part-time students, and managers who choose a travel mode from among the public transport, bicycle, walking and private car to satisfy their travel needs to the university.

7.2.1 The Aim and Objectives

The specific aim of this case study is to test the effectiveness of MOSH methodology in understanding individual travellers' decision variables and how the travel requirements considerations impact on their mode choice decisions.

To achieve the aim, the set objectives include, to:

1) Investigate which of the travel requirements (i.e., physical, cognitive, and affective) is paramount to travellers' mode choice.
2) Examine how resources within the transport system's environment influence travellers' perceptions of the travel requirements.
3) Examine the impact of policy interventions on travellers' satisfaction, physical, cognitive and affective considerations as well as travellers' mode adoption pattern.
4) Examine the impact of social interactions on the travellers' mode choices.

7.2.2 Hypotheses for Purpose Achievement

The criteria for purpose achievement include the following working hypotheses:

- Levels of physical, cognitive and affective considerations impact on travellers' travel mode satisfaction.
- Interventions on travel mode's reliability, comfort, safety, convenience, journey-time, personal-mobility and value for money constraints of travel systems influence travellers' physical, cognitive and affective requirement considerations.
- Understanding individuals or group of travellers' abilities regarding their physical, cognitive and affective considerations assist in stimulating their behaviours.
- Interventions on reliability, comfort, convenience, journey-time, safety, personal mobility and value for money constraints of travel system influence travellers' mode shift behaviour.

To adequately answered the set hypotheses, the following knowledge-gathering procedures are taken into consideration.

7.3 Knowledge Gathering

In order to construct intuitive and psychological questions, focus group discussions with documents analysis provided enough background information that enabled relevant questions to be drawn for the survey.

7.3.1 Focus group meetings

Focus group discussions method was used to unveil typical transport users' views on several factors (both psychological and ergonomics) in the identified problem's area. Common terms to be used in the study by the project team were defined for each of the identified factors and concepts. This is to ensure easy reference and to promote communication among the members of the project team at various stages of the study. The contents and the nature of the questions were reviewed to ensure that they measure all relevant elements to the study.

The holistic views of the system's elements and processes that are relevant to the study are taken. The elements are the needs that a traveller wishes to satisfy which include an *efficient, safe* and *comfortable journey* to and from the university; relevant travel mode aspects that support travellers' needs; the transport system facilities to achieve the needs and the measurable terms to evaluate the performance of the transport system regarding the travellers' needs. Lastly, the views and contributions of each participant in the meetings form the contents of the first draft of the questions to be presented to the respondents.

7.3.2 The Questionnaire Design

The questionnaire for this study (Appendix B) included questions tailored towards mode-related scenarios so as to ensure neutrality in both the affect and the utility measures of the attributes being investigated (Steg, 2005). The questions focused on: *ease of accessing information, reliability of available information, ease of getting to the 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 elements*. Further validation and reviews of the questions were made by consulting experts in Human Factors and transport operations. The two sections in the questionnaire are the demographic section for participant responses on the basic information such as age, sex, occupation etc.; and the travel mode's attributes perceptions that consist of Likert scale and open-ended questions. Each Likert scale questions requires two responses, one to answer *"how satisfying*", and the second to answer *"how important"* the travel mode's attribute under consideration is to the respondents as discussed in Section 5.3.1.5. The two responses are needed to generate travellers' *affective* display of their decision.

7.4 Data Collection

The administration of the questionnaires was through online and physical distributions of the printed form. This is to enable enough data to be collected and allows more extensive representations among respondents within the university community.

There are 348 respondents to the survey questionnaire with the following distributions:

- 82 cyclists comprised of 37 females and 45 males, aged between 20 and 56 years.
- 81 personal vehicle users comprised of 46 female and 34 males aged between 18 and 63 years.

- 93 public transport users comprised 46 female and 47 males aged between 16 and 45 years.
- 92 pedestrians comprised of 31 female and 59 males aged between 18 and 63 years, and 2 pedestrians who preferred not to declare their gender.

7.5 Analytic Processes

The analytic steps involve data cleaning up, the building of the relationship table (Table 7.1), the construction of a PCA-AH, and learning the stereotypes within each traveller's population.

7.5.1 Data Cleaning and Organisation

The table in Table 7.1 is constructed to aid the linear views of the relationship that exists among the travel mode's attributes, the related transport systems' concepts and the criteria for performance evaluation. The description of the columns in Table 7.1 are as follows:

1) Column one of the table contains the list of the travel mode-specific attributes considered (e.g., ease of accessing information). Each of which is related to one or more elements in column two.

Table 7.1: Travel mode's Attributes, Concepts and Performance Criteria for performance Table

The aspect of transport system investigated	The related transport system concepts	Criteria for performance evaluation
-Ease of accessing information.	Information Provision.	Journey Time.
-Reliability of available information.	Timeliness of the travel mode.	
-Ease of getting to destination on time.	Reliability of the travel mode.	Reliability.
-Ease of getting to main travel mode.	Speed of the travel mode.	
-Getting On and Off the mode.	Frequency of the travel mode.	Cost and Value for Money.
-Distance to the main mode.		
-Parking Space concern.	Physical Ability.	Security.
-Delays.	Security.	Comfort.
-Security en-route the mode.	Safety.	
-Safety on the main mode.		Convenience.
-Availability of Road signs.	Protection from Poor Weather.	
-Attitude of other road users.		Personal Mobility.
-Walking from the main mode to destination.	Autonomy/Privacy/Journey Control.	
-Protection from weather.		

2) Column two has the defined travel modes' main concepts selected for investigation among the travellers' identified concerns. The selected concepts are those that are relevant to the achievement of the study's aims.

3) Column three contains the criteria for performance evaluation used to measure how well the transport systems satisfy the needs of travellers on each of the items in column two.

For illustration, looking at the travel mode's concepts (column two), it can be observed that *information provision*, *timeliness*, *reliability, speed,* and *frequency of the travel mode* are required to making judgements about the travel mode's *journey-time* performance (column three). The same applies to other criteria for measuring system performance.
Next section presents the building of the AH and the representation of the physical, cognitive and affective (PCA) considerations at each level of travellers' decisions.

7.5.2 The Construction of the Study's Abstraction Hierarchy

The AH in Figure 7.1 shows the structural representation of the links that exist among the transport system's resources, the investigated concepts, the performance measuring terms and the travellers' needs. The AH is constructed using the traditional AH's *'how-what-why'* triad (Section 2.11.1). For illustration, if the focus is on the highlighted nodes; and the *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 a *comfortable* journey at the *functional purpose* level of the system. That is, it can be seen that *convenience (what)* occurs to ensure that *comfort(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 was used to form all the links on the AH. Also, travellers' perceptions regarding their situations (temporal and spatial) and the functions they can perform at these situations have physical, cognitive and emotional considerations. The three travel requirements (i.e., PCA) are represented in Figure 7.1 with the solid filled blue, red and green coloured circles respectively as explained in Section 5.3.1.6.

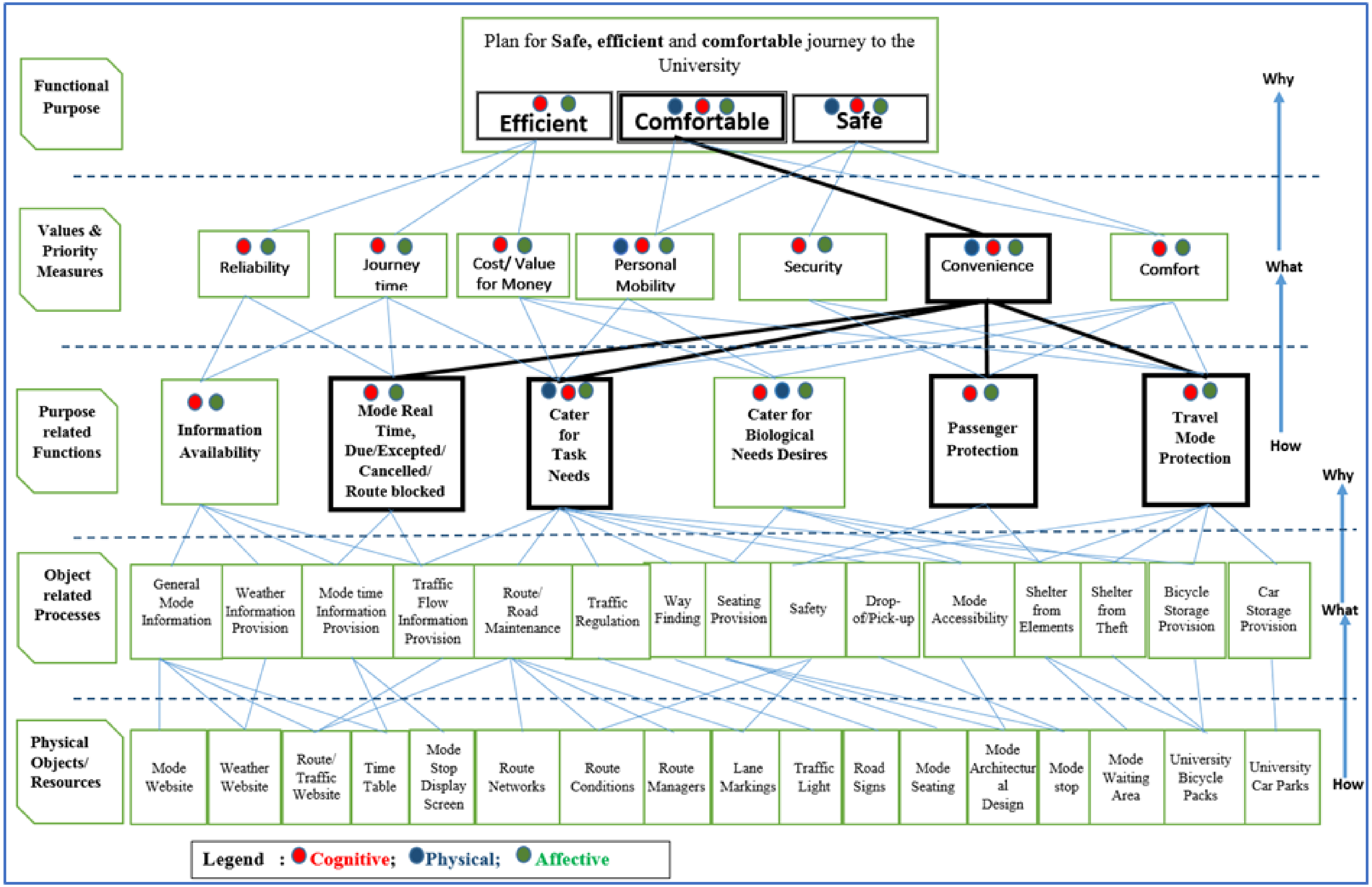

Figure 7.1: The Physical-Cognitive-Affective Abstraction Hierarchy

The presence of any of the colours at a node in the AH is an indication that the travel requirement it represents is considered. The PCA representations are indicated only at the *purpose related functions, values and priority measures and functional purpose levels,* of the AH. This is due to travellers' perceptions that are user-dependent at the three levels. The construction of the AH regarding this case study is explained as follows:

Functional Purpose

The provision of *efficient*, *comfortable* and *safe* travel to and from the university is the functional purpose of the travel modes. An e*fficient* transport system has a direct link to costs and time. The traveller's need for *comfort* includes flexibility in journey control, privacy and autonomy, good seating provisions, etc. Lastly, travellers' *safety* has links to a secure and healthy environment; safe walkways for pedestrian, clearly marked lanes for the cyclist, traffic light and road signs, and security at all times.

Values and priority measures

Seven measurable concepts with which travellers judge their travel mode performances are explained as follows:

- ***Reliability*** measures how closely the actual journey times relates to the advertised or expected schedules. The node that represents *reliability* in the AH indicates that traveller's perceptions involve cognitive and affective considerations. It c include cognitive in order to access and understand the schedule of the mode. But there is no physical activity demanded from a traveller to access available information.
- ***Journey-time*** is the criteria for measuring travellers' perception regarding the time taken to travel to and from home to the University. The PCA representation of *journey-time* indicates that traveller perception involves both cognitive and affective considerations.
- ***Cost and value for money*** metrics measures travellers' perception of the achievements of certain *tasks needs* and *biological needs.* The cost savings for the individual travellers could include an efficient road network, while the values for money can be measured by the level of satisfaction on the facilities (e.g., parking space) within the university. The PCA representations for the *Cost and value for money* indicate that travellers are involved in both cognitive and affective considerations.
- ***Personal mobility*** has a strong link to the traveller's conveniences in terms of mode accessibility. It also relates to personal safety in that a disabled-friendly travel mode will be safer to use for all traveller from the design's point of view**.** The *personal mobility* node in the figure indicates the inclusion of physical consideration in addition to the cognitive and affective aspects of the perceptions.
- ***Security and safety*** are the measures for a safe trip to and from the university, it includes the activities and behaviours of other road users, availability of road signs and traffic management facilities. The PCA requirements consideration in the security node indicates only the cognitive and affective consideration while the physical consideration is missing due to its less-relevance to the measure.
- The ***Conveniences*** measure include the needs such as parking space, ease of getting on and off the mode, good road networks, etc., which are critical to mode choice

decision. For instance, inadequate maintenance of cycle lanes during heavy snow could make cycling difficult. The conveniences measure involve the three travel requirement considerations.

- ***Comfort*** is the ability or inability of a travel mode to provide for users' *biological needs*. For example, cares for seating space and shelter from elements can impact on the travellers' decision on travel mode choice.

Purpose-related functions

The three categories of purpose-related functions associated with different purposes in this study are: 1) the *information provision* function. 2) the *catering for passengers tasks and biological needs* function and 3) the *protection* function. The PCA representation is indicated in each node.

Object-related processes

The process of using the related resources mentioned in the *physical objects* level to achieve the functional purpose of a travel mode to the university is considered at this level. These processes are to some extent out of the users' direct control. It is important to state that there is no indication of PCA at this level of the AH because the *processes* are traveller's independent.

Physical Objects/resource

The *physical objects* level is populated with the transport system's objects and resources within the city and university environments. These objects and resources are those identified during the focus meetings and that are necessary for users to achieve the purpose of their journey to the university.

7.5.3 The Construction of Contextual Activity Template

Modelling of travellers' functions and situations with the Contextual Activity Template (CAT) is presented in this section.

Figure 7.2 is a general CAT for all categories of travellers investigated in this case study. The six identifiable situations in a traveller's journey to and from the university 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 functions at the vertical axis are the *information provision, catering for passengers' task and biological needs, and the protection functions.*

The *origin and the destination* situation represent the travellers' home or the University. In Figure 7.2 it can be seen that *origin/destination* supports all functions except *wayfinding*. The function of wayfinding can only occur while a traveller is already on the journey.

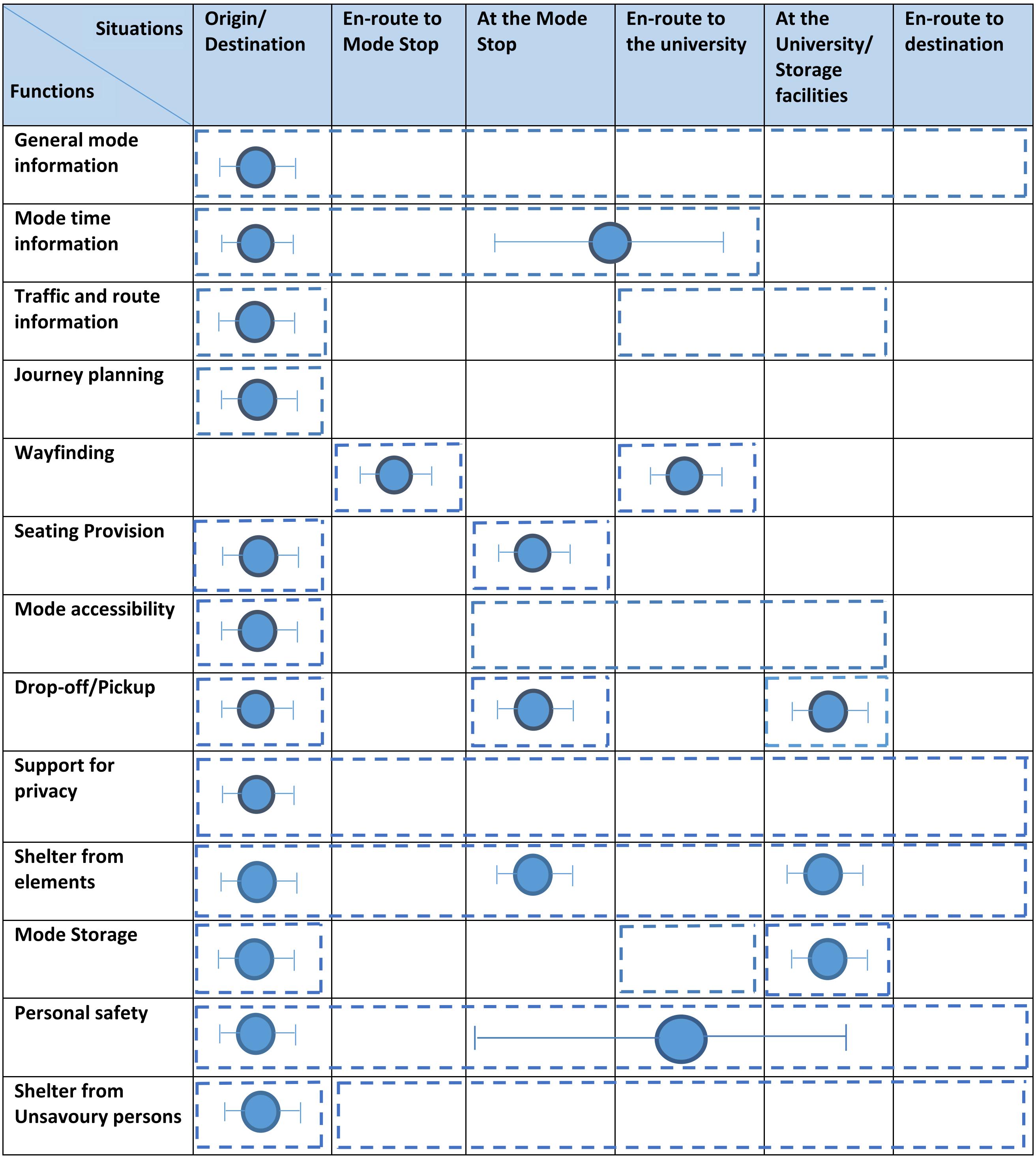

Figure 7.2: The Study's Contextual Activity Template. Adapted from Stanton et al., (2013)

The *En-route to Mode Stop* and *En-route to the university* situations applied to public transport users moving from home/university to the bus stop. Figure 7.2 shows that there are a few functions that could occur but typically do not (dashed box) especially in the areas of general information seeking and protections. This is due to those functions related to information accessibility that assumed the common ways of accessing information with computers at home or workplaces. However, with the advances in technology (e.g., Wi-Fi) such functions could occur in the indicated situations (e.g., en-route to mode stop). Also, the function of general protections that include *support for privacy, shelter from elements, mode* *storage, personal safety* and *shelter from unsavoury persons* do not occur at the *en-route to mode stop and en-route to university situations*. The dashed boxes indicate that those functions could occur but typically do not. At the *mode stop* and *the university/ storage facilities* situations majority of activities can take place. The functions of *protection from unsavoury persons* and *support for privacy* cannot. The dashed boxes indicate that the functions can take place with the presence of security agents at the mode stop or the university storage area when necessary.

The following section presents CAT for the different travellers' categories with the inclusion of the PCA considerations.

7.5.4 Contextual Activity Template with Physical, Cognitive and Affective Indications

All CATs in this section are constructed with the inclusion of PCA considerations under different situations. In general, the three travel requirements are always present in all travellers' situations and functions. Although some requirements might not be so important to support decision-making in a given situation hence, they are not indicated with colours in the CAT. The presence of a coloured circle in any of the cells indicates that the travel requirement(s) it represents is necessary for the function to occur in that situation. However, due to variability in travellers abilities, different weight are attached to different requirements.

Travellers' observable daily travel activities and the survey data are used to allocate the travel requirements. Functions and situations that are relevant to each group of travellers are included in their respective CAT. Only the CAT for the public transport user is shown in this section while the CAT for the cyclist, car users and the pedestrians are detailed in Appendices C2, E2 and F2 respectively.

All functions in the CAT-PCA required public transport users' *cognitive* and *affective* considerations. In addition, the *journey planning, wayfinding* and *mode accessibility* functions required travellers' physical efforts while the *seating provision* support only influence travellers' affective judgement. The function of *general information provision* could occur at the *mode stop* and *en-route to the University* (situations) but typically do not (dashed box). However, this function can be made available with the advances in technology (e.g., offline information outside Internet coverage). The measure can increase the travellers' satisfaction regarding travel modes' information provisions. Generally, provision for *protection* gives rooms for improvements in the en-route to the university and en-route to the destination as shown with the dashed boxes for the *support for privacy, shelter from elements, personal safety, and shelter from unsavoury persons.*

Public transport users' Contextual Activity Template with Physical, Cognitive and Affective Indications

The public transport users' contextual activity template with physical, cognitive and affective (CAT-PCA) considerations is shown in Figure 7.3.

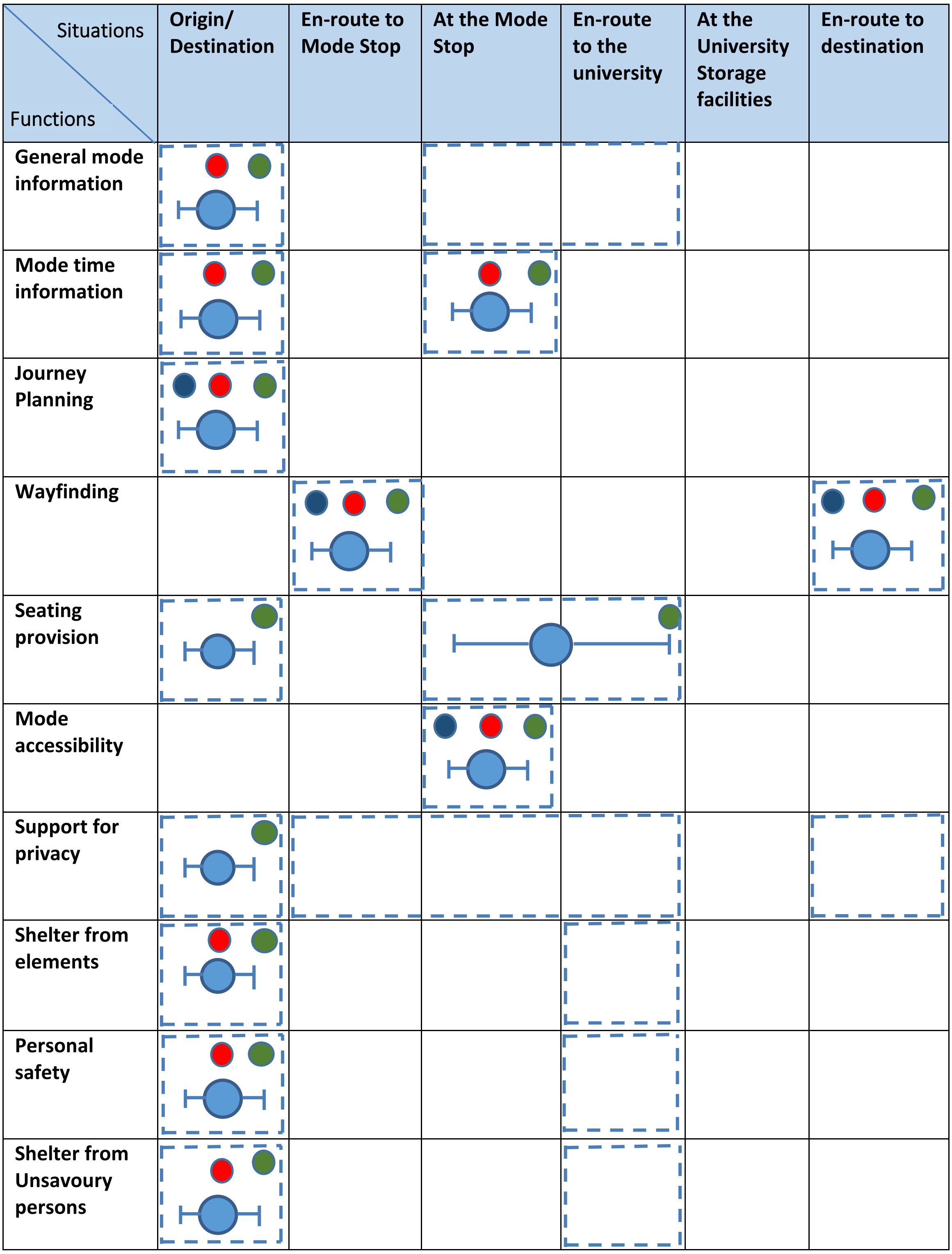

Figure 7.3: Public transport-user Contextual Activity Template with PCA Indications

The next section presents the data analytic processes for the derivation of the travellers' physical, cognitive and affective perception from the survey data and the classification process to identify various stereotype groups.

7.6 Data Analysis

The analysis of the data is in two parts: the analysis of descriptive data and the analysis of qualitative data for all categories of travellers.

7.6.1 Analysis of Descriptive Data

There are two sets of values for the analysis: the travellers' perceptions of how important the investigated concepts regarding their needs are, and the travellers' perceptions of how satisfied they are. Q13 is about the travellers' perceived importance attached to each of the travel mode concepts investigated regarding their needs. The values assigned for the range of responses to Q13 are: "0: very unimportant", "0.25: "somewhat unimportant" "0.5: neither important nor unimportant", "0.75: somewhat important", "1: very important", "1.25: Not Applicable" for all attributes considered.

The question in Q14 collects responses on the travellers' perceived satisfaction regarding their needs on the investigated concepts. The values assigned for the range of responses to Q14 are: "0: very unsatisfied", "0.25: "somewhat unsatisfied" "0.5: neither satisfied nor unsatisfied", "0.75: somewhat satisfied", "1: very satisfied", "1.25: Not Applicable" for all attributes considered.

The resulting dataset from the response to questions Q13 and Q14 are the needed information to generate the physical, cognitive and affective components of travellers' perceptions as discussed in the following sections.

Derivation of the Traveller's Affective Display (Emotional) Perception from the Survey Data

The two variables required to derive the affective component of the traveller's decision are the *importance* and the *satisfaction* regarding a travel mode's concepts.
The two entries form the input into the Affective generator engine (fuzzy inference system) discussed in Section 5.3.1.7. The sample table for the affective display values is shown in Figure 7.4. The same process applies to all travel modes' concepts considered for all categories of travel modes.

	A	B	C
1	Cyclist-Safety:Satisfaction	Cyclist-Safety:Importance	Cyclist-Safety AffectiveValue
2	0.25	1	0.367978949
3	0.75	0.75	0.698839807
4	0.5	0.75	0.595009561
5	0.75	1	0.735785282
6	0.75	0.75	0.698839807
7	0.75	1	0.735785282
8	0.75	1	0.735785282
9	0.25	0	0.227708142
10	0.5	0.75	0.595009561
11	0.25	0.75	0.331284651
12	1	0	0.672875198
13	1	1	0.783549912
14	0.75	0.75	0.698839807
15	1	0.5	0.743465854
16	1	1	0.783549912
17	0.5	1	0.607426778
18	0.75	1	0.735785282
19	0.5	1	0.607426778
20	0.75	1	0.735785282

Figure 7.4: Sample Output from the Affective Generator System

Derivation of the Traveller's Physical and Cognitive Perceptions from the Survey Data

The datasets on the travellers' satisfaction for all the travel mode concepts are classified to be either cognitively or physically relevant as explained in Section 5.3.1.7. For example, the question '*how satisfied are you with the ease of getting to your main mode*' in the case of public transport users, refer to their perceptions of both the physical ability required to walk to the main mode (e.g., bus stop) and the mental capacity to know how to get to the bus stop at the right time. However, some questions will either be physically or cognitively relevant. For instance, questions such as '*how satisfied are you with the reliability of available information about your travel mode*' is only relevant to the cognitive aspect of travellers' perception. Having derived the affective, physical and cognitive perceptions for all the concepts of travel mode considered the three travel requirements (i.e., PCA) values are recorded for each concept.

Further analytic verification was performed on the datasets for the three travel requirements using correlation analysis. The intention is to enable the identification of highly correlated concepts so as to reduce to a manageable size the number of travel modes' attributes to be included in the classification process. The results of the analysis showed a high correlation between the average affective satisfaction and corresponding cognitive and physical values (as indicated in the result tables in Appendices C1, D1, E1 and F1). This outcome indicates that there is sufficient reliability in the expert knowledge that generates the affective display values.

Learning the Stereotypes within the Travellers' Population

The resulting datasets from the previous analytic processes were classified using the K-Medoids clustering also known as partitioning around medoids (PAM) algorithm. The choice of K-Medoids is because it is less sensitive to noise and outliers when compared with the common K-means method, although it requires a pre-specified number of clusters 'K' just like the K-means method. Hence, the 'Elbow' method for determining the optimum number of clusters in a dataset was used to identify the best number of clusters for each of the traveller's group before the application of the K-Medoids algorithm. The outputs of the analysis indicate that three clusters each described the members in the public transport, car, and pedestrian users' groups, while four clusters are found to be suitable for the cyclist group. The box plots that represent the cyclists, public transport users, pedestrians and car users' populations are presented in Appendices C3, D3, E3 and F3 respectively.

The open-ended responses are analysed in the next section with the intention is to identify individual travellers' specific concerns and their suggested solutions to the concerns.

7.6.2 Qualitative Analysis of Textual Data

The following are the summary of the results of the analysis for the four travel modes considered.

(i) The Textual Analysis of Cyclists' Concerns and Suggested solutions

Table C2 (Appendix C) summarises the areas of concerns to the cyclists. From the table, all suggested solutions made by the cyclists centred around five values and priority measures of *safety, journey time, comfort, convenience and personal mobility*. This is due to the concerns for bad weather, the attitude of other road users, cycle lane obstructions and lack of route maintenance, inadequate cycle sheds and traffic delays etc. The strategies to stimulate cyclists' behaviours are formulated using the information provided in the table.

(ii) The Textual Analysis of Public transport users' Concerns and Suggested solutions

Table D2 (Appendix D) summarises the concerns of public transport users to the University and suggestions for possible solutions. The concerns include the *reliability* of the bus schedules, and *journey-time* due to delays; *convenience* regarding ease of getting to the bus stop as well as walking to the destination; *comfort* in the aspects of sitting provisions and protection from elements at the bus stop. The suggested possible solutions regarding the concerns are categorised to be related to four values and priority measures of *reliability, journey time, comfort and convenience*.

(iii) The Textual Analysis of Pedestrians' Concerns and Suggested solutions

The pedestrians' concerns and the possible suggestions are summarised in Table E2 (Appendix E). The pedestrians perceived as unsatisfied their *comfort* experience regarding bad weather; hindrances to *personal mobility* as a result of pavements cutting edges and crossing facilities too far apart. Also, their *safety* and *security* due to other road users' attitude as well as reliable weather information. The possible suggestions on how to resolve some of the current problems are classified under the following aspects of values and priority measures: *reliability, journey time, comfort, safety, and personal mobility*.

(iv) The Textual Analysis of Car Users' Concerns and Suggested solutions

Table F2 (Appendix F) contains the car users concerns in making journeys to the university and the suggested solutions to address the concerns. The information provided in the table indicates that car users are more concerned about *delays* and *journey time* due to traffic jams that occur at the junctions. There are also concerns about the limited parking space and high parking fees in the university as well as the need to have access to real-time information about traffic flow in the city. Summarily, the car users' concerns are categorised into *reliability, journey time, Costs and value for money, comfort* and *convenience* aspects of values and priority measures.

7.6.3 Policy Formulation and Strategic Intervention Development

Based on the identified concerns in Section 7.6.2, the strategies for intervention are formulated with the assistance of the CAT analysis output for each travellers' groups. The interventions are provided from HF and PSY perspectives in the form of campaigns, legislation, incentives (e.g., reduced parking fee) and provision of necessary infrastructures. Each strategy is targeted at a theme of concerns (e.g., delays, parking space concerns). The following gives general details of various strategies and policies formulated for interventions, and the areas where the interventions are provided:

(a) Reliability

The reliabilities in the context of this study includes travel mode's operations and information provisions which are the main concerned to all categories of travellers. Pedestrians, car users and public transport users are concerned about the reliability of general information. In summary, the challenges associated with reliability typically result in delays in travellers' journey which has an associated emotional impact.

The strategies for interventions regarding information and travel mode reliability are formulated to include: offline information access (when there are no installed Internet connections). The current advances in technology (mobile devices), which ordinarily does not represent the norm and traditional ways of accessing information can be explored to provide software applications that support off-line use (i.e. working like off-line maps). In addition, an increase in the numbers of buses may ensure that the bus schedules are close to the advertised time as possible. Provision of timely information about possible diversions due to road crashes or constructions to assist in planning ahead. The improvements due to the interventions in the aspect of information and travel mode reliability could impact on the *cognitive* efforts required in accessing and using the information. It could also improve the *convenience and efficiency needs* satisfaction as well as the overall satisfaction of the travellers.

(b) Journey-Time

All categories of travellers have varying concerns regarding their journey time to the university. For instance, cyclists are concerned about road obstructions due to indiscriminate parking of vehicles on the cycle lane which caused their frequent mounting and dismounting from the cycle. The strategies for interventions on travellers' journey-time include: Legislation and fines against road obstructions, timely information provisions well ahead of time before constructions begin may address journey-time issues of different categories of travellers. Widening the roads around the junctions will reduce the delays due to queue when light releases traffic and more vehicles can flow. Dedicated lanes for public buses, increase in the numbers of buses could reduce the delays and hence, improve public transport users' journey-time. The interventions could impact on travellers' overall experience and the perceived travel mode *efficiency* in terms of travel time, and also improve the cognitive demand required to satisfy the needs.

(c) Costs and Value for Money: only private

The concerns regarding the costs and value for money is primarily on the perceived cost and the benefits of services delivered by the transport system. For car users, the inadequacy in parking space makes available parking space far away from the final destinations. Also, the high rate of the current parking fee coupled with individual costs of car maintenance are of concerns. The possible interventions to the value for money concerns are the provision of more parking space and downward review of parking fee especially for students who own cars. However, the intention of stakeholders could be to stimulate the behaviours of car users to adopt other travel modes to the university. Hence, the non-implementation of the suggested interventions might serve as another strategy to discourage the use of private cars.

(d) Personality Mobility

The measure of travellers' personal mobility is related to the ease of access or movement within the transport environment. In this respect, a group of travellers may be constrained on the *ease of getting on and off* the travel mode. For instance, cyclists and pedestrians perceived the blockage of cycle lane and pathways as restricting their mobilities. Hence, the intervention regarding personal mobility focuses on the provision of a friendly design for better access to the mode. This will also be helpful for people with special needs such as aged and mobility-impaired travellers. A more access friendly travel mode could impact on the travellers' perception regarding the physical and cognitive requirements for mobility, which in turn could improve their *safety* and *comfort* perceptions as well as the overall satisfaction.

(e) Safety/Security

There are varying concerns regarding travellers' security and safety of the travellers and their travel mode to the university and their travel modes. The concerns of cyclists and pedestrians regarding safety are about the attitude of motorists which they perceived as life endangered. In addition, the incidences that could occur due to the opened and cutting edges of the walkways/cycle lanes as well as inadequate crossing facilities. The public transport users identified the unusual behaviour of some passengers during the journey as concerns. In addition to safety issues, the cyclists' security concerns include cycle theft due to inadequate locked up sheds.

The general interventions for safety and security are the provisions of well-marked and dedicated cycle lane, more secured cycle sheds or security CCTV where there are no locked sheds for the cyclists. Regular maintenance of walkways, campaigns on the right of respective road users and fines for bad road use habit. The presence of university security agents or community protection officer at strategic places can improve travellers' confidence and encourage the usage of travel mode perceived as less safe. The measure could impact on the travellers' emotions for being more secure and safe.

(f) Convenience

For the concerns related to travellers' conveniences, public transport users are concerned about the ease of getting to the main travel mode, and distance to the main mode. The car users' convenience related concern is in the areas of finding suitable parking space that is not far from the final destination. Some cyclists and pedestrians find the road crossing facilities too far apart in some cases and consider this not convenient. The provided interventions include the introduction of local-link buses on the routes not currently serviced and more user-friendly mode accessibility designs to address public transport issues. Installation of more crossing facilities at intervals to reduce the distance between successive crossing installations for both cyclists and pedestrians. More parking spaces be built close to the academic areas where offices are located. The measures would alleviate travellers' conveniences concerns and improve the PCA considerations in satisfying the needs.

(c) Comfort

All categories of travellers except car users have varying concerns regarding their comfort, mostly on protection from bad weather due to inadequate covers. In addition, public transport users are dissatisfied with inadequate seating provisions sometimes during peak hours. The suggested solutions as interventions regarding travellers' comfort include the provision of bigger shelters along cycle lanes and walkways for travellers who may wish to have stopover due to bad weather; configuring the traffic lights at junctions to give priority to cyclist and pedestrians especially during bad weathers (e.g. rain, snow); campaigns and sensitisation for other road users to give priority to cyclists at junctions especially during bad weather. An increase in the number of buses or provision of buses with additional seating facilities will address seating concerns of the public transport users.

7.7 Model Development

7.7.1 Model Conceptualisation

The conceptual flow diagram in Figure 7.5 is an adaptation of the MOSH framework described in Chapter 4, in modelling travellers mode choice scenario. The figure provides the conceptual overview of activities and daily decision processes of a set of travellers to a university and how policy intervention can influence the decision process.

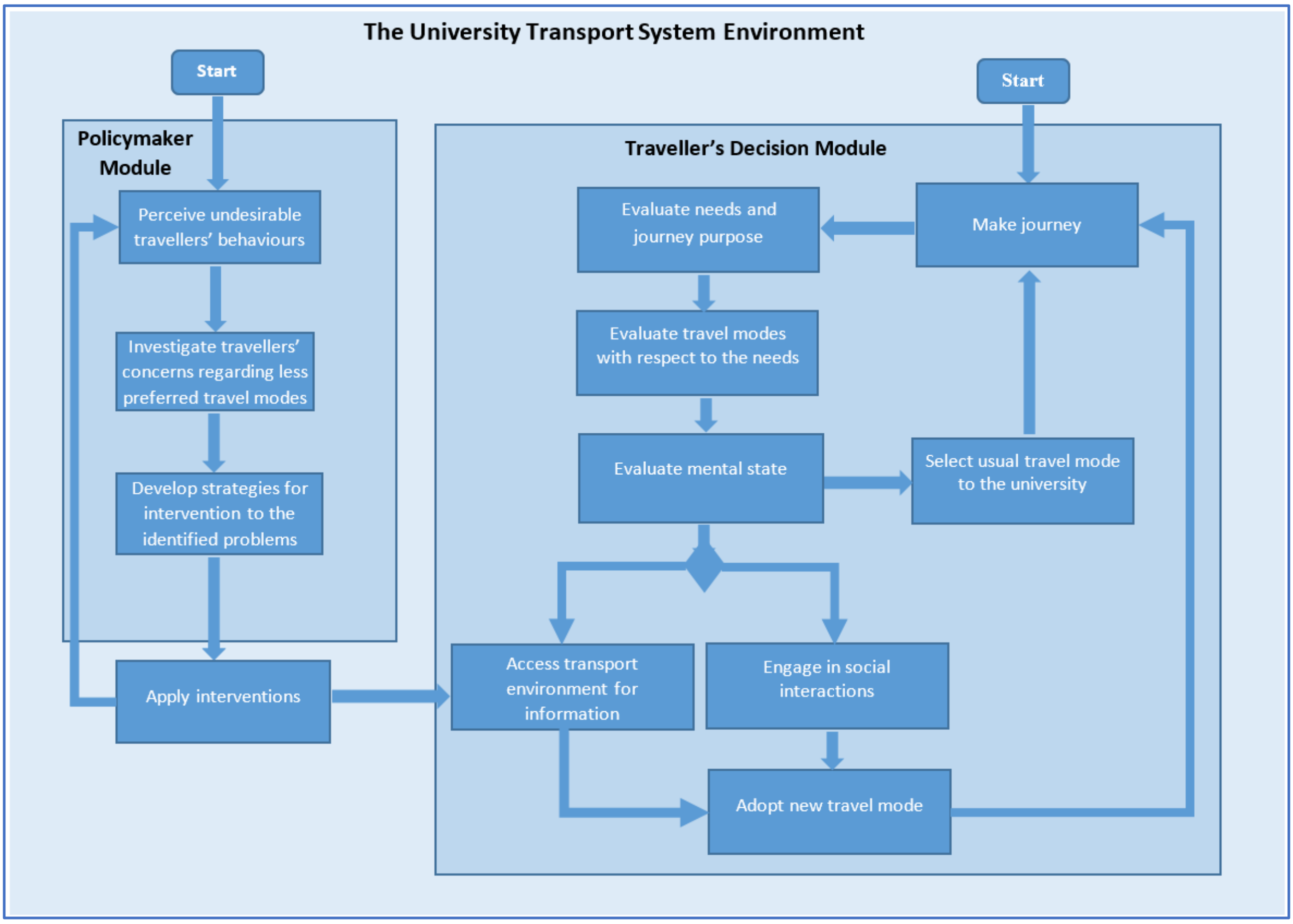

Figure 7.5: Traveller's Decision process Conceptual diagram

The policymaker (the left box in the figure) is the university transport management, the county and transport companies that perceive and investigate the causes of unpleasant situations observed in the environment due to travellers' behaviours. They also develop the strategy for interventions from the knowledge gained through the investigation to alleviate their concerns. The policymaker is only active when there is a perceived unpleasant situation in the environment. Hence, it is not in the same time step as the traveller agent who makes decision often.

As depicted in Figure 7.5, each simulation cycle represents one journey making process in the agent's world. Travellers plan to make a journey to the university by first evaluate the travel mode for their needs. The travellers then considered the available travel modes with respect to those needs based on their previous experiences. The evaluation process updates their mental states using their memories and behavioural control. The travellers have in their memories the past experiences regarding the journey and the capability of the travel modes to satisfy their needs. Behavioural control is the ability possessed by the travellers (e.g., physical, cognitive and affective abilities) to use the modes and the ability demanded by various travel modes. Travellers can choose from among bicycle, public transport, private car and walking. Also, at the end of each journey, travellers can make a comprehensive evaluation of their chosen travel mode for *satisfaction* and *certainty.*

Travellers' mental status represents their current state which determines the information-seeking strategy to use in order to increase their knowledge of other travel modes in the environment if dissatisfied or uncertain. In general, a *satisfied* and *certain* traveller continues using the usual travel mode without seeking new information, but a *dissatisfied* or *uncertain* traveller will engage in either social interactions with other travellers or optimise their own knowledge with information from the environment. The information-seeking process if successful leads to the adoption of a new travel mode.

7.7.2 Use Cases

The use case in *Figure* 7.6 extends the general use case templates provided in Section 5.3.2.

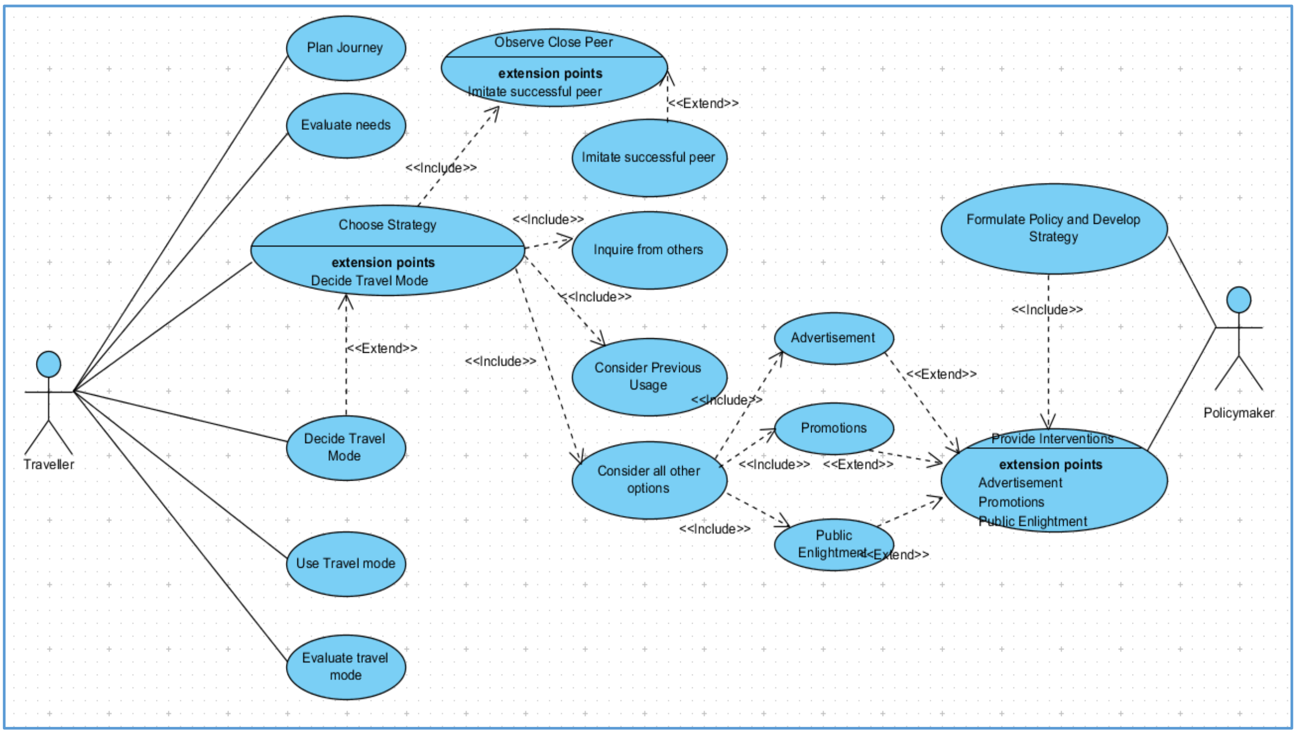

Figure 7.6: Use case diagram for Travellers to a University

The use case indicates that a traveller *plans* for a journey while at the origin by *evaluating* the available travel modes with respect to their personal needs. The traveller can also *choose a strategy* that will lead to a satisfying choice among the available travel modes in the system. Travellers' information-seeking strategies include *observing close peers*; this activity can extend to *imitating* successful peer and make an *inquiry* from others. In addition, a traveller can *consider its own previous option* of making a journey or *consider all other options* (i.e., including interventions). The traveller can also *decide* on suitable travel modes to *choose* after a successful decision, then *make use of the chosen travel mode.* It can then *evaluates* how the chosen travel mode meets its needs at the end of the journey.

The second actor in the diagram is the policymaker (i.e., stakeholders) who investigates the perceived unpleasant situations in the system environment; develop strategies for interventions and then apply the interventions to the environment.

7.7.3 Model Structure

The class diagrams in Figure 7.7, Figure 7.8 and Figure 7.9 are adapted from the MOSH methodology general Class diagram. The diagrams are used to represent the relevant structures of the current study.

(a) The TravelMode class diagram Figure 7.7 is adapted from the Opportunity Abstract class (Section 5.3.2) with four travel mode instances i.e., cycle, personal vehicle (car), walking, and public transport.

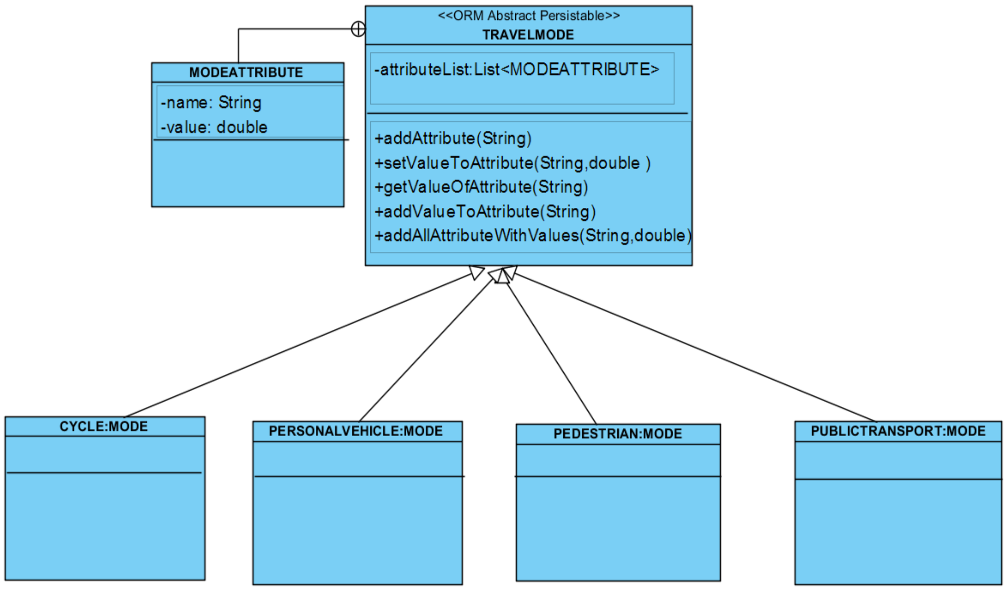

Figure 7.7: Travel mode Class diagram

(b) Figure 7.8 shows the classes that represent the structure of the TravellerType Class and

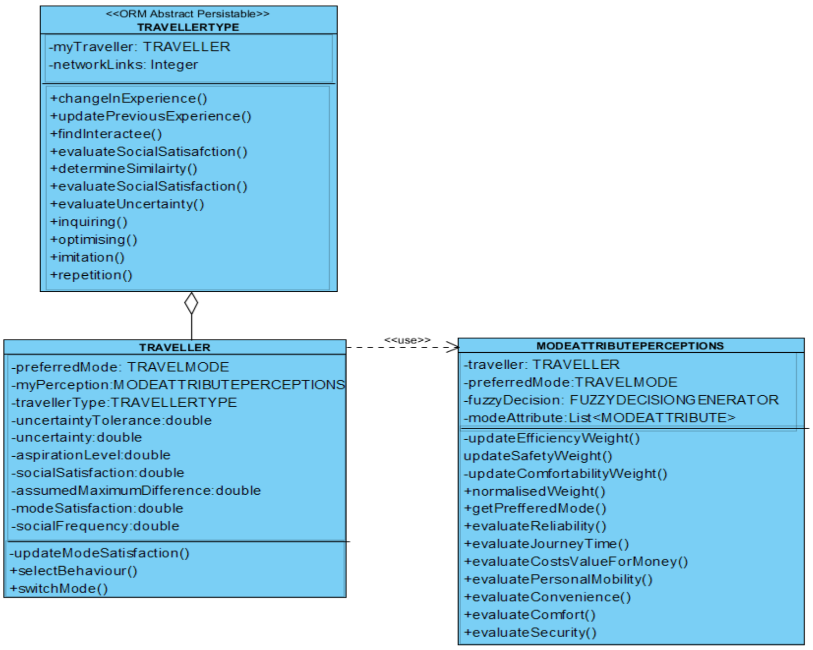

Figure 7.8: Traveller Agent's Class diagram

Traveller Class which are adapted from the AgentType Class and Agent Class (Section 5.3.2) respectively. The Traveller class is a specific traveller with attributes. In this study, the Traveller Class contain a *ModeAttributePerception* class that shows the structure of the Travellers' perception module.

(c) Figure 7.9 represents the general structure of the policymaker which is adapted without any changes.

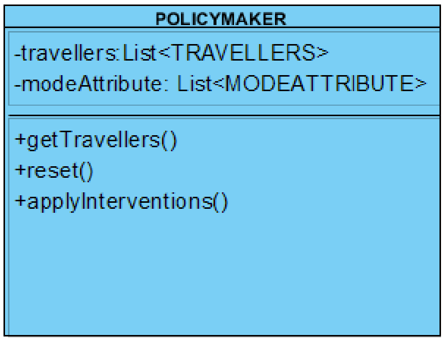

Figure 7.9: Policymaker Agent Class diagram

7.7.1 Traveller Behaviour

The state machine diagram in Figure 7.10 captures the Traveller Agent physical states. It indicates that a traveller can be at the origin/source planning for the journey, be travelling or decided not to travel.

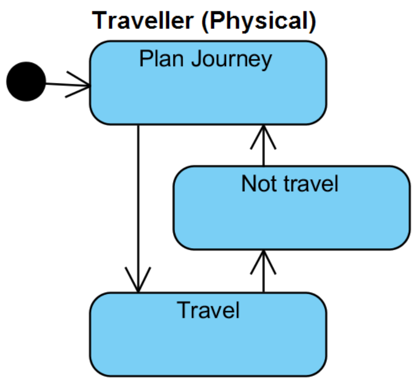

Figure 7.10: Traveller Agent State machine diagram

In the model design, the following assumptions were made:

- the likelihood of a traveller to invest in a new travel mode such as buying a bicycle or car for the purpose of making a journey is not considered.
- all travellers have physical, cognitive and affective requirements to make use of their chosen travel mode.
- travellers already have previous experiences of their journey to the university.
- travellers who visit secondary places are not considered in the simulation.

The simplification is that travellers always make use of the chosen travel mode to and from the university.

7.7.2 Experimental Factors

The following specifies the experimental factors used as inputs into the simulation model.

- Demographics of the population (e.g. age, gender, occupation, disability, etc.)
- Ratio between travellers' population (e.g. cyclists, car-users pedestrians, and public transport users)
- Ratio between stereotype groups.
- Traveller's perceptions regarding the three travel requirements.
- Traveller's initial prefer travel mode.
- Social network settings (e.g. social frequency, inter-agent difference)
- Policy choice to stimulate travellers' behaviour.

These experimental settings allow us to create all scenarios required at the experimentation stage.

7.7.3 Responses

The identified outputs expected to be collected from the models in response to policy interventions are:

- Time series graph to visualise travellers' average daily satisfaction.
- Time series graph to visualise the travellers' average daily physical, cognitive, and affective considerations.
- Time series graph to visualise the travellers' mode shift diffusion pattern.

The first two responses help to check hypothesis 1 and 2 and the accomplishment of the simulation model's objectives 1 and 2 of the study. The third response assists to check hypothesis 3 and the accomplishment of the simulation model's objectives 3 and 4.

7.8 Model Implementation

In the implementation of the model design, relevant sections of the MOSH libraries templates are used as follows:

7.8.1 Travel Mode

The travel modes' concepts to be investigated are added to the *Opportunity.java* as the attributes of the travel modes using the *addattribute* method of the class. The four categories of travel modes, that is public transport, private car, bicycle and walking are created as classes extended from the abstract *Opportunity.java.* This automatically extends the added attributes to the four concrete classes.

7.8.2 Traveller Agent

There is one *Traveller* agent class that is capable of using any of the four travel modes at different times. Each traveller agent is initialised with the *preferred mode* and the *traveller type* attributes. The *preferred mode* attribute holds the current traveller's travel mode, and the *traveller type* indicates the description of the traveller (e.g. cyclists, pedestrian, etc.).

Travellers Decision Driving factors

The traveller's decision driving factors are: level of ambition on the needs, the needs' weight, social networks' influence, and uncertainty and uncertainty tolerance. Travellers attached different *importance* to different aspects of their travel mode needs which reflects on their ambitions.

The traveller's *ambition* is expressed as:

$$AmbitionNeeds_i = \frac{\sum_{j=1}^{n} Importance\_PriorityMeasure}{n} \qquad \text{Equation 7.1}$$

Where:

$AmbitionNeeds_i$ is the traveller's ambition on need i;
$\sum_{j=1}^{n} Importance\_PriorityMeasure$ is the travellers' importance response on related *values and priority measures* that contribute to the travellers' need i, and n is the total numbers of such measures involved.

The needs weight is the normalised *importance* values for the travellers' needs indexed between 0 and 1 (Section 5.3.1.7). The needs weight of agent a on need i is given by:

$$NeedsWeight_i = \frac{AmbitionNeeds_i}{\sum_i^n AmbitionNeeds} \qquad \text{Equation 7.2}$$

Where:

$AmbitionNeeds_i$ is the ambition value for traveller's need i; and $\sum_i^n AmbitionNeeds$ is the sum of ambition values for all the needs (i.e. the set of needs) considered.

The needs weight is used to obtain the relative utility of each need to travellers' satisfaction and used to factor the traveller's satisfaction as shown in Equation 7.5.

The social weight of a traveller is evaluated from its social needs. Since it is needed when a traveller is engaging in social interactions, the weight for each of the three social aspects (i.e., *conformity, anti-conformity,* and *superiority*) is evaluated and initialized at this point in the simulation by calling the '*socialSatisfaction*' method (Section 5.3.2.8) of the MOSH methodology. The social evaluation is based on the travellers' similarities. The similarities are evaluated based on the traveller's *occupation, travel mode type, distance range* etc., describe in Section 7.9.1.

The uncertainty value is expressed as:

$$Uncertainty_t = Satisfaction_t < Satisfaction_{t-1} \qquad \text{Equation 7.3}$$

Where:

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

The *Traveller's uncertainty tolerance* values could not be initialized using the survey data, hence, a Gaussian random sample was drawn for each of the travellers at the moment of initialization. The effect of which was observed on the model's behaviour by varying the random sample value and with hypothesis testing at the verification and validation stage in Section 7.8.5.

Traveller's Needs

The travellers' needs include the *efficiency* need; the *comfort need;* and the *safety* of both the traveller and the travel mode.

The level of traveller's satisfaction on the three needs are derived as follows:

$$LevelOfNeedsSatisfaction_i = \frac{\sum_i^n Values\&PriorityMeasure}{n} \qquad \textit{Equation 7.4}$$

Where:

$LevelOfNeedsSatisfaction_i$ is the traveller's satisfaction on need i; $\sum_{p=1}^n Values\&PriorityMeasure$ is the travellers' satisfaction levels on related *values and priority measures* that contribute to the traveller need i, and n is the total numbers of such values and priority measures involved.

Traveller's Needs Satisfaction

Traveller's *satisfaction* is derived from the satisfaction of the three identified needs (efficiency, comfort, and safety) (Equations 7.4) and their associated weight (Equation 7.2) using the Cobb-Douglas utility functions derivatives as follows:

$$TravellerSatisfaction = \prod_{n=1}^n LevelOfNeedsSatisfaction_i^{NeedsWeight_i} \qquad \textit{Equation 7.5}$$

Where:

$TravellerSatisfaction$ *is* the traveller's overall satisfaction regarding a travel mode; $LevelOfNeedsSatisfaction_i$ is the traveller's satisfaction on need i, and $NeedsWeight_i$ is the weight a traveller attached to need i.

The choice of utility function's Law of Constant Returns to Scale to evaluate traveller's satisfaction is to generate an output that will be proportional to the changes in inputs factors. In addition, to factor the resulting value to a number between 0 (minimum) and 1 (maximum). All the parameters stated above determine the traveller's mental state and information-seeking strategies.

Traveller's perception on Physical, Cognitive and Affective Considerations

The traveller's PCA perceptions on each of the travel mode's attributes are evaluated as discussed in Section 5.1.3.6.

A typical traveller decision comes from the combinations of linguistic labels of the travel requirements (e.g *pleasant physical consideration*, *unpleasant cognitive consideration* and *neither-pleasant-nor-unpleasant affective perceptions)*. Each of these linguistic labels also has the strength (the degree) they contributed to a decision. The listing in Algorithm 7.1 represents the steps in identifying the linguistic labels (e.g. pleasant, unpleasant, etc.) and their strengths in the travellers' decision.

Algorithm 7.1: Identifying travel requirements contributions and strengths

Identifying travel requirements that contribute to traveller's decision and their strengths

There are 3 inputs: physical, cognitive and affective each with 3 linguistic labels: Pleasant, Unpleasant and NeitherPleasantNorUnpleasant into the fuzzy system

```
Declare a Vector v  to return multiple values
set the input i //i_1 = physical, i_2 = cognitive, i_3 = affective
get rule r.size   // r.size is the total number of rules in the fuzzy system rule base
for each r do
   for each x do//x = the linguistic labels
    get the variable x . name   ⊳ =  name
    get the variable x . Input  ⊳  = crisp input
   get the variable x. Firing Strength ⊳ = strength
      if (strength >=0)
         Map.put (name, strength)
   end for
endfor
v.add(Map)
v.add(Perception)
end.
```

The expected outputs from the algorithms are:

(i) the name of the input variable that contributes to the travellers' mode choice decision (i.e. physical, cognitive, affective).
(ii) the linguistic labels (p*leasant, unpleasant, neither-pleasant-nor-unpleasant, etc.*) that form the inputs into the system and the respective strengths they contributed to the travellers' decisions, and
(iii) the travellers' actual perception of the concepts being considered.

7.8.3 Policymaker Agent

The policymaker agent in the simulation is the agent through which the policy interventions are applied to the system.

7.8.4 Build the Context For the Project

The Context for this project contains the *traveller* agent, the *policymaker* agent and the projections. The process of building a Repast ContextBuilder as detailed in Section 5.3.3.1 is adapted.

7.8.5 Model Validation and Verification

Several of the simulation models' validation and verification techniques suggested by Law (2008) and (Law & Kelton, 1991) were used in ensuring the credibility of the model. Firstly, we verified that the model is programmed correctly, and the algorithms have been implemented appropriately. Secondly, experts in relevant disciplines such as Human Factors transport research and ABM were consulted to validate the model. The experts had earlier reviewed the questions at the data collection stage to ensure relevant data were collected. In addition, they reviewed how the simulation was developed, so as to ensure that it represents the real world with sufficient accuracy for the purpose. More validations were ensured through various outputs generated from the simulation, these include the high-level correlation results on the physical, and cognitive perceptions and that of the affective data.

As part of the validation process, a confidence-interval approach using paired-t hypotheses testing (Law & Kelton, 1991) was done for two pairs of travellers' parameters: 1) satisfaction/ambition level and 2) uncertainty/certainty level.

Hypotheses and outcomes are summarised in Table 7.2 and Table 7.3.

Table 7.2: 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

Since p-value >α of the hypothesis confirmed that travellers are satisfied when the satisfaction is smaller or equal to their ambition level.

Table 7.3: Hypothesis testing: uncertainty/certainty level

Null hypothesis	H_o Travellers are *certain* when their certainty level <= their uncertainty tolerance level
Alternative hypothesis	H_a: Travellers are certain when their certainty level >their uncertainty tolerance level
Population of travellers	600
T	3.7988
Df	599
p-value	0.999

The hypothesis on travellers' uncertainty/certainty confirmed that travellers are certain when their certainty is smaller or equal to their certainty tolerance level.

7.9 Model Calibration

The formalisation of the empirical data on the travellers' perceptions of their travel mode is represented in this section.

7.9.1 Traveller Agents Initialisation

To initialise the traveller agent for the simulation model, descriptive data from the questionnaire (Appendix B) was used to set up the 348 respondents stated in Section 7.4. The rest of this section describes the link between the data from the questionnaire and the traveller agent's parameters.

Demographical information

Each agent has demographic information that includes: gender, age, designation (e.g. full-time student, lecturer etc.) disability status, average daily distance covered, frequency of mode usage, preferred travel mode, etc.
Q1 and Q2 provide information about the sex and age of the travellers to the university. The information on gender was taken without adjustment, while the age was normalised to fit the value space for the simulation. Q12 provides information about travellers' *disability*. The answer to the disability question ranges between 0 and 5, and the values directly correspond to how much it affects mode choice; with value 5 has (all the time), 4 has (often) down to 0 which implies (no disability).

Traveller's perception of the *importance* of a travel mode's attributes

To formalise the aspect of travellers' perceptions on the importance of a travel mode's attributes. The travellers' responses to Q 13 ranges from "-1: very unimportant" to "1: very important" with not applicable values (N/A) represented as "1.5". The responses are used to instantiate the traveller's *ambition* and *needs weight.*

Traveller's perception of the *satisfaction* of a travel mode's attributes

Travellers' responses to Q 14 on the level of satisfaction regarding a travel mode are used. The responses range from "-1: very unsatisfied" to "1: very satisfied" with not applicable values (N/A) represented as "1.5".

The Physical, cognitive and affective considerations

The lower and upper bound values for the corresponding satisfaction on PCA considerations and the proportion of various groups within the population are used to initialise the simulation model within each travel mode category using the *'getValueOfAttribute'* method in the Traveller Class of the MOSH methodology library.

Mode selection criteria

The following are the major mode selection criteria used by the traveller:

- Daily distance range: Q9 provides information for travellers' daily average distance travel round trip in miles. The distance ranges are: "less than five miles"; "between five and ten miles"; "between ten and twenty-five miles"; and "above twenty-five miles". The proportion of the population of each travel mode alternatives that belongs to the distance range category is used in setting up the value for the travellers.

- Rate of mode usage: participants' responses to Q11 provides information on the frequency with which the travellers used their preferred travel mode. There are eight values that correspond to: (1) "every day"; (2) "3 or more times in a week"; (3) "once or twice a week"; (4) " 1 or 2 times a month"; (5) "once every 2-3 months"; (6) "once every 4-6 months"; (7) "less often"; and (8) "first time today". The answers are copied without any adjustments to initialise the travellers' frequency of travel mode usage.

- Occupation: is the designation of a traveller within the university community. Q5 provides information about travellers. There are 10 categories of occupation that are converted to values ranging from 1 to 10.

7.9.2 Travel Mode (Opportunity) Initialisation

The travel modes considered in this study are public transport, private car, bicycle and walking. They are initialised with the numbers of users of each mode as specified in Section 7.9.1. Each of the travel modes consists of specific attributes on which traveller's view are sought. The value for each of the attributes regarding their physical, cognitive, and affective perceptions is initialised from the results of the analysis stage using the "*setValueToAttribute*" method of the Mode Class.

7.10 Experimentation

7.10.1 Design of Experiment and Execution

To achieve the aim of understanding travellers' response to travel requirements, three scenarios were studied:

i. base scenario.
ii. combined intervention scenarios that include all strategies to address travellers' concerns.
iii. selected strategies targeted at specific groups within a traveller population.

The results of the experiments were observed on travellers':

i average daily satisfaction
ii average daily physical, cognitive, and affective (PCA) considerations.
iii travel mode diffusion pattern.

The simulation runtime was set to 365 days with 25 replications to account for randomness in the parameterisation process. A warm-up period of 5 days was considered to remove initialisation bias. The experiments are based on the information provided by the AH (Section 7.5.2), the CAT-PCAs (Section 7.5.4), and the classification analysis (Section 7.6.1) of each travellers' population.

7.10.2 Base scenario

The default run of the simulation as parameterised with the survey data is presented in this section. It also serves as the basis against which the impact of the policy interventions and the travellers' travel mode shift patterns are compared.

Base scenario's average daily satisfaction

Figure 7.11 shows the default travellers' average daily satisfaction on the four modes.

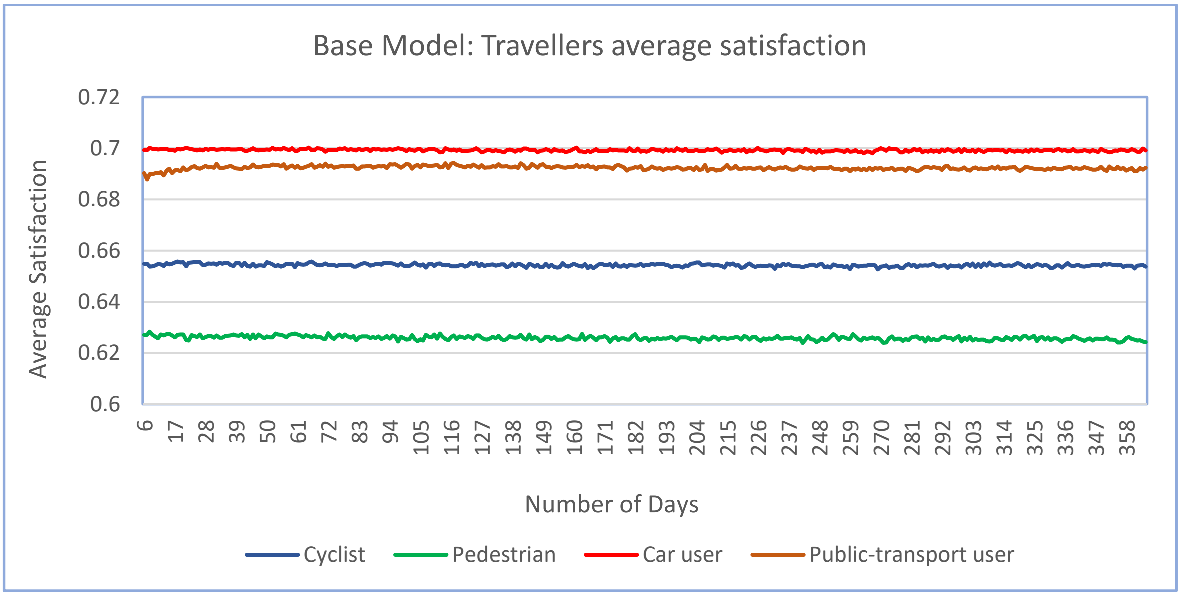

Figure 7.11: Average daily satisfaction

The early steady states observed is a direct representation of travellers' default level of satisfaction. The series indicates that car users are more satisfied than other categories of users with an average daily satisfaction level of 71%. The public transport user's category has 68.5% and the cyclist group has 65.8% average daily satisfaction respectively. The pedestrians are relatively satisfied with 62.8% average satisfaction and the least satisfied among the categories.

Base scenario's traveller mode shift pattern

Figure 7.12 presents the graph of the base scenario for travellers' travel mode shift pattern. The University transport system that the simulation represents is an operational system. The simulation starts with an empty system; therefore, a point is observed where the aggregate number in each category of travellers appear steady. In the graph, the adoption pattern becomes relatively stable after day 70, which is then selected as the intervention point for the experimentation.

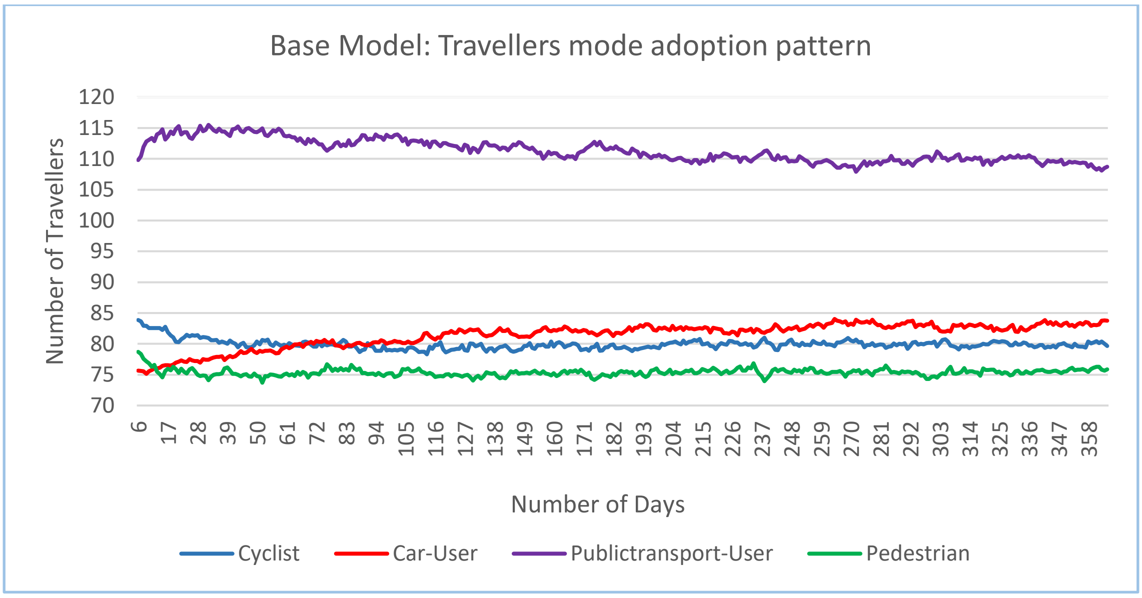

Figure 7.12:Base scenario Travellers' mode adoption pattern

The observed changes in the numbers of various categories of travellers in *Figure* 7.12 can be attributed to their interactions among travellers while seeking ways to satisfy their travel needs.

In the following experimentation section, the *base scenario* time series of the *average daily satisfaction* and *average daily PCA satisfaction* for respective travel modes are arranged with the experimental scenarios time series for easy comparison.

7.10.3 Experimentation on the Cyclists

The cyclists' concerns regarding their journey to the University are the *journey time, comfort, convenience, safety* and *personal mobility* of the cycling environment.

The three sets of scenarios investigated are:

(1) the combined interventions that involved all strategies to alleviate cyclists' concerns.

(2) the safety-comfort interventions for the concerned cyclists (i.e., two-strategy).
(3) The journey time, convenience, and mobility interventions (i.e., three-strategy).

The Cyclists' average daily satisfaction

Figure 7.13 presents the cyclists' average daily satisfaction time series. Figure 7.13(a) is the time series for the base scenario with which the intervention scenarios are compared. Figure 7.13(b) shows the combined interventions that involved all the five strategies. Figure 7.13(c) is the *comfort and safety* interventions (i.e. two-strategy intervention).

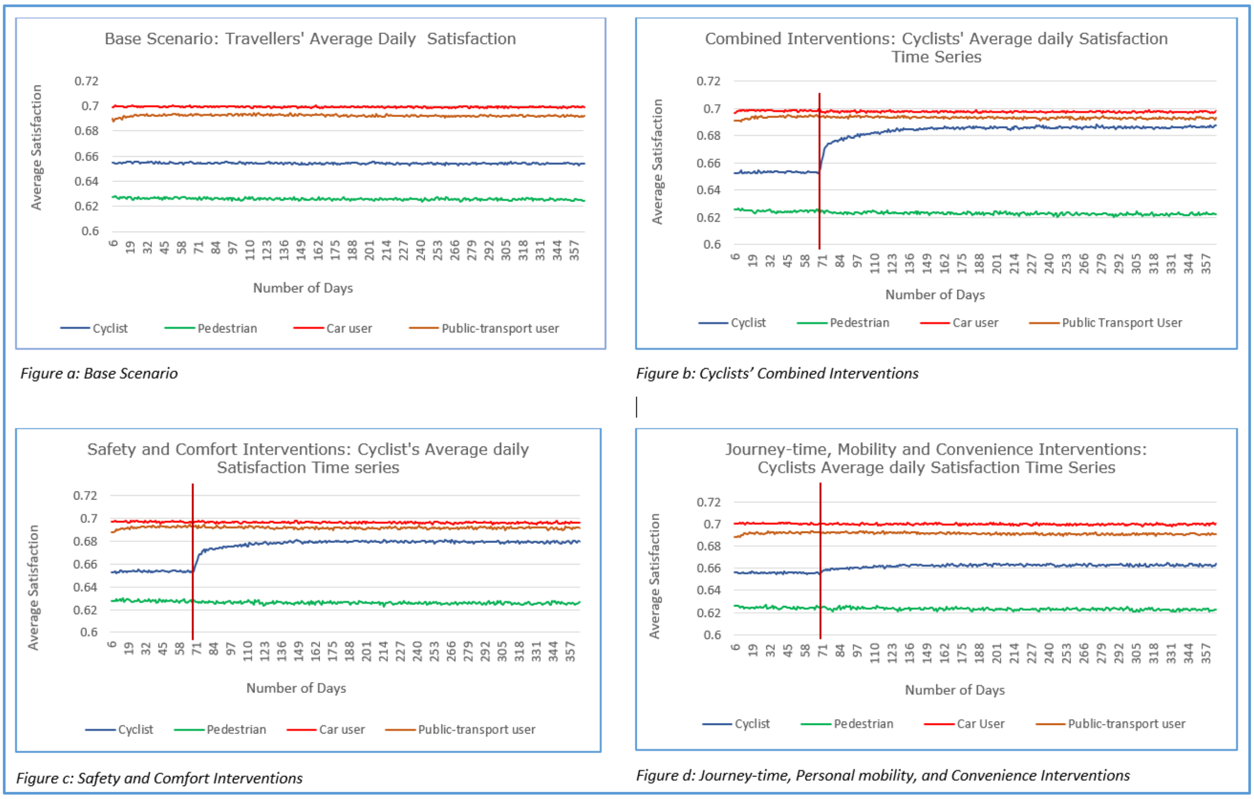

Figure 7.13: Cyclists' average daily satisfaction

Figure 7.13(d) is the intervention that combined *journey-time, personal mobility* and *convenience* strategies (i.e. three-strategy intervention). All the interventions are applied at day 70 (i.e. red line point). Comparing the average daily satisfaction in the four graphs indicates that the combined intervention and the two-strategy intervention provide observable increases of 0.027 unit (i.e., 3.75%) and 0.023 unit (i.e., 3.13%) respectively, while the three-strategy intervention produced an improvement of 0.01 unit (2.36%). It implies that the combined interventions (Figure 7.13(b)) perform better than the two-strategy intervention (Figure 7.13(c)) by 0.004 unit (i.e. 0.56%), and better than the three-strategy intervention (Figure 7.13(d)) by 0.017 unit (2.36%). It can be argued that the difference in satisfaction level in response to different interventions can be attributed to the importance that the cyclists attached to the respective constraints and the proportion of the population that is concerned. It is evident from the experiment that cyclists' safety and comfort are more important to them than the journey-time and convenience, hence, have more influence on their behaviour.

Cyclists' physical, cognitive and affective requirements consideration

Figure 7.14 is the time series for the cyclist' average daily PCA considerations in satisfying their needs. Figure 7.14(a) is the base scenario graph which indicates that cognitive and physical efforts are more considered by the cyclists in their decision-making processes than the affective aspect.

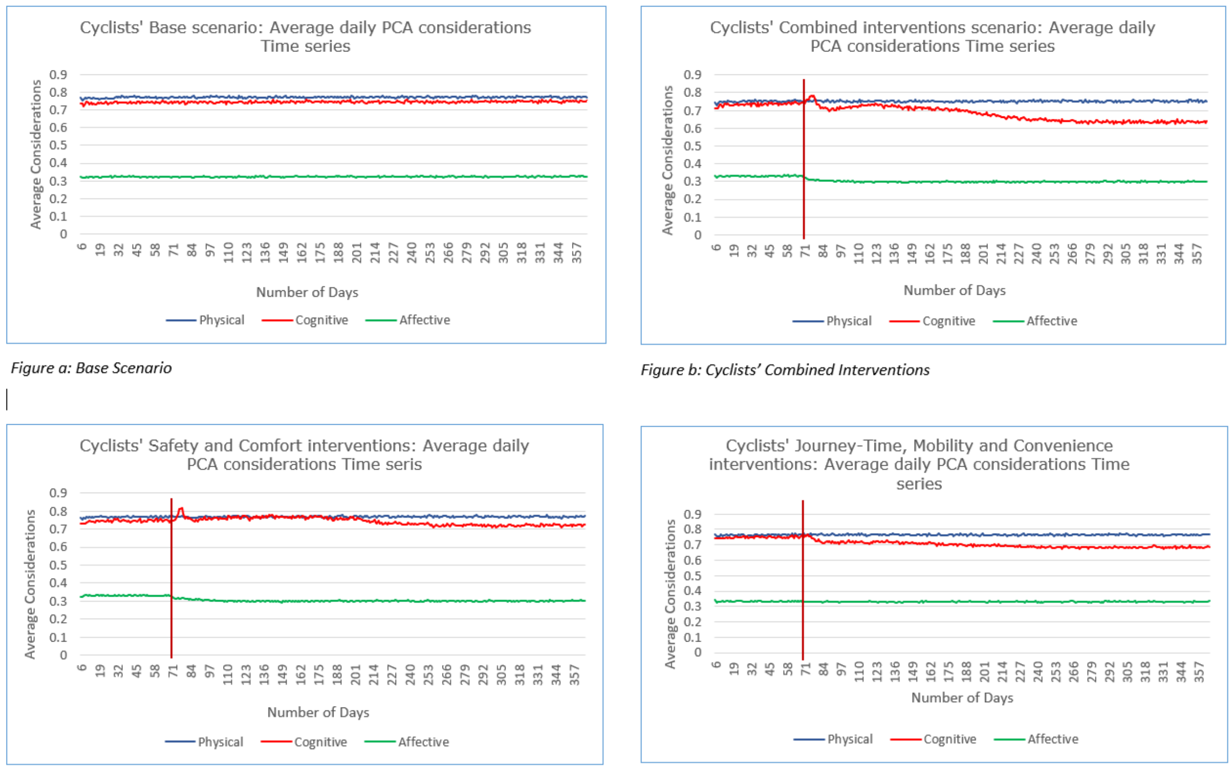

Figure a: Base Scenario

Figure b: Cyclists' Combined Interventions

Figure c: Safety and Comfort Interventions

Figure d: Journey-time, Personal mobility, and Convenience Interventions

Figure 7.14: Cyclist population average daily PCA considerations

The high level of cognitive considerations can be attributed to the cyclists' concerns for safety that requires adequate journey planning. Cyclists perceived physical efforts as a necessary requirement to cycle. The major emotional concerns considered by the most cyclist is the *safety* of the cycling environment and the comfort from weather protections. However, the issue of cyclists' *protection from elements* is generally considered as a hard constraint that could be difficult to address. Therefore, they do not consider it as a major concern in this study which forms the reason for low affective consideration expressed in the figure.

Figure 7.14(b) is the time-series graph showing the cyclist PCA considerations in response to the combined interventions. The figure shows an initial increase in the average daily *cognitive* considerations due to travellers engagement in evaluating how the new intervention will benefit their concerns. This is followed by a gradual decrease in the level of *cognitive* consideration until a steady state of 0.62 is reached at day 276. This behaviour explains that those who had earlier involved in planning to know how best to benefit from the intervention had acquired the needed information and hence, make decisions with less thinking.

Moreover, in Figure 7.14(b), the average daily *physical* consideration remains constant because the intervention does not influence the level of physical efforts required in cycling. A reduction can be seen on the *affective* consideration level due to emotional improvement as a result of the reductions in *cognitive* efforts to achieve needs satisfaction.
Comparing the two-strategy and three-strategy interventions, the two graphs showed a significant reduction in *cognitive* consideration which come earlier in the three-strategy intervention than in the two-strategy. The behaviour can be attributed to the ergonomics nature of concerns involved in the three-strategy intervention (i.e., construction of route with direct links with fewer junctions) the impact of which manifest faster in travellers' behaviours. The behaviour in Figure 7.14(c) (i.e., the *two-strategy intervention)* explains that it takes a longer period for many of the cyclists to appreciate the benefit of interventions on the *safety* and *comfort* (i.e., psychological) hence, a longer period to reflect on their planning efforts. Although, the *safety and comfort* intervention has an immediate influence on their affective consideration due to improvements in the concerns.

One insight from this scenario is that travellers responded quickly to ergonomics related interventions than to the psychological factors. However, further investigation may be required to establish which of the factors last longer when the interventions are withdrawn.
Another important insight from this scenario is that cyclists' engaged in more cognitive considerations than in the other travel requirements for their mode decision process due to planning for a safe route and journey time. One more insight is that the *affective* consideration is associated more with the travellers' *safety* and *comfort,* which are more psychological than the other concerns which are ergonomic factors. Also, the level of travellers' participation in cognitive processing is a function of the importance that a traveller attached to the travel mode's constraints or attributes to satisfy a need. Therefore, it is important that intervention is targeted at the travel modes' attributes that are more important to travellers. It is evident from the scenario that improvements in the travel mode's *journey time, comfort, convenience, safety,* and *personal mobility* through interventions improve travellers' PCA considerations. Therefore, focussing on the interventions that can reduce travellers' cognitive considerations in the cycling environment can increase the likelihood of more travellers adopting cycling.

7.10.4 Experimentation on Public transport users

The following are the interventions targeted at the constraints regarding *reliability, journey time, comfort, and convenience* expressed by the public transport users. The three sets of scenarios investigated are:

(1) the *combined* interventions that involve all the four strategies for public transport users.
(2) the *comfort* intervention targeted at a group within the population
(3) The *journey time* intervention for the concerned public transport users. The two interventions targetted at the two travel mode attributes are informed by the identified stereotypes in the population.

Public transport users' average daily satisfaction

Figure 7.15 presents public transport users' average daily satisfaction time series. Figure 7.15(a) is the base scenario with which the intervention scenarios are compared. Figure 7.15(b) shows the time series for the combined interventions of the four strategies. Figure 7.15(c) is the time series for *comfort* intervention.

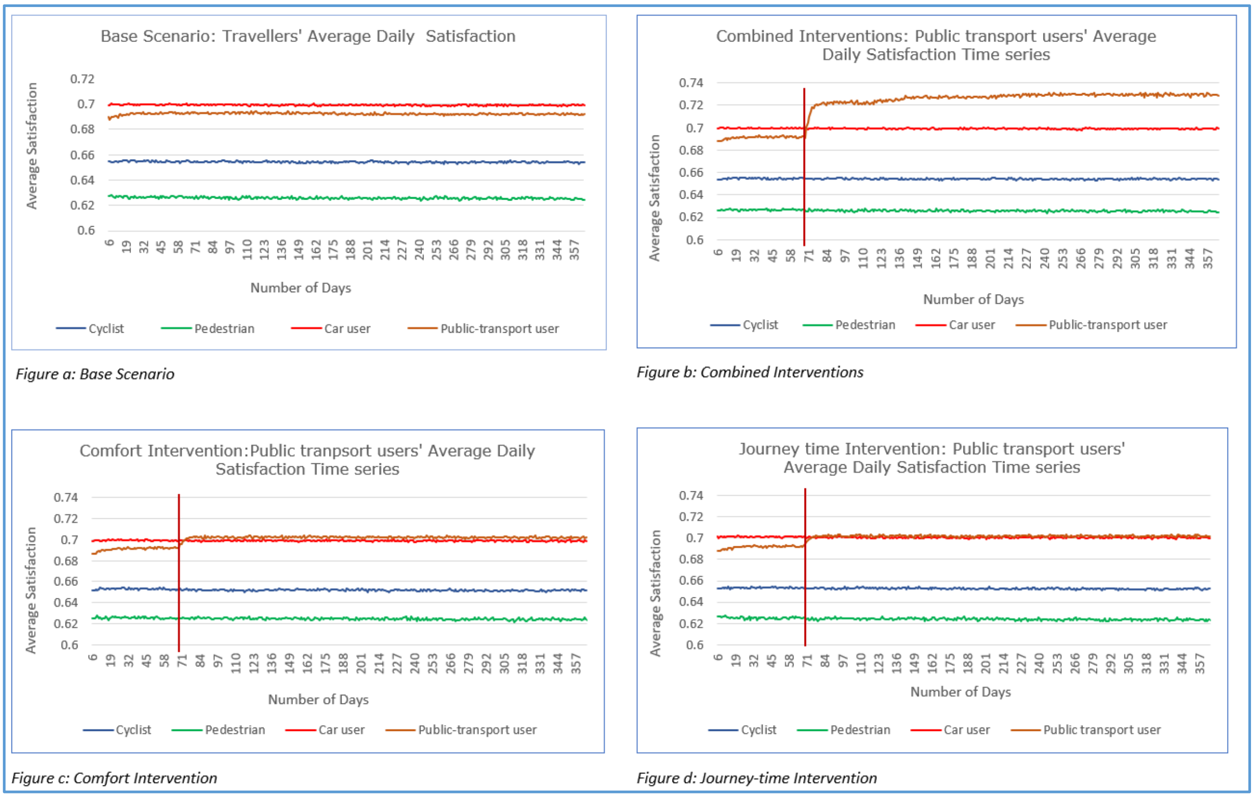

Figure 7.15: Public transport users' average daily satisfaction

Figure 7.15(d) shows the time series for *journey-time* intervention. All the interventions are applied on day 70. Comparing Figure 7.15(b, c and d) with the base scenario. The combine intervention (Figure 7.15(b)) have an increase of 0.05 unit (i.e. 6.76%) of average daily satisfaction; In (Figure 7.15(c)), the *comfort* intervention produces an increase of 0.02 unit (i.e., 2.70%) while the journey-time intervention in Figure 7.15(d) produces an increase of 0.015 unit (i.e. 2.02%)of average daily satisfaction. From the scenarios, the performance of the combined intervention can be attributed to the influence of interdependency of the system's constraints on each other. It can be argued that in developing a strategy to stimulate public transport users' behaviour, considerable improvements can be achieved when all the strategies designed for the constraints are combined. Therefore, to improve the public transport users' satisfaction, interventions must include all aspects of concerns expressed by the travellers.

Public transport users' physical, cognitive and affective requirements considerations

Figure 7.16 is the time series showing average daily PCA considerations by public transport users.

The base scenario in Figure 7.16(a) indicates that the *cognitive* aspect of travel requirements is considered most by public transport users in their decision-making process. This can be attributed to the mental requirement to plan around the bus schedules and to seek and understand available general information related to the journey. The physical considerations usually come from the need to walk to and from the bus stop.

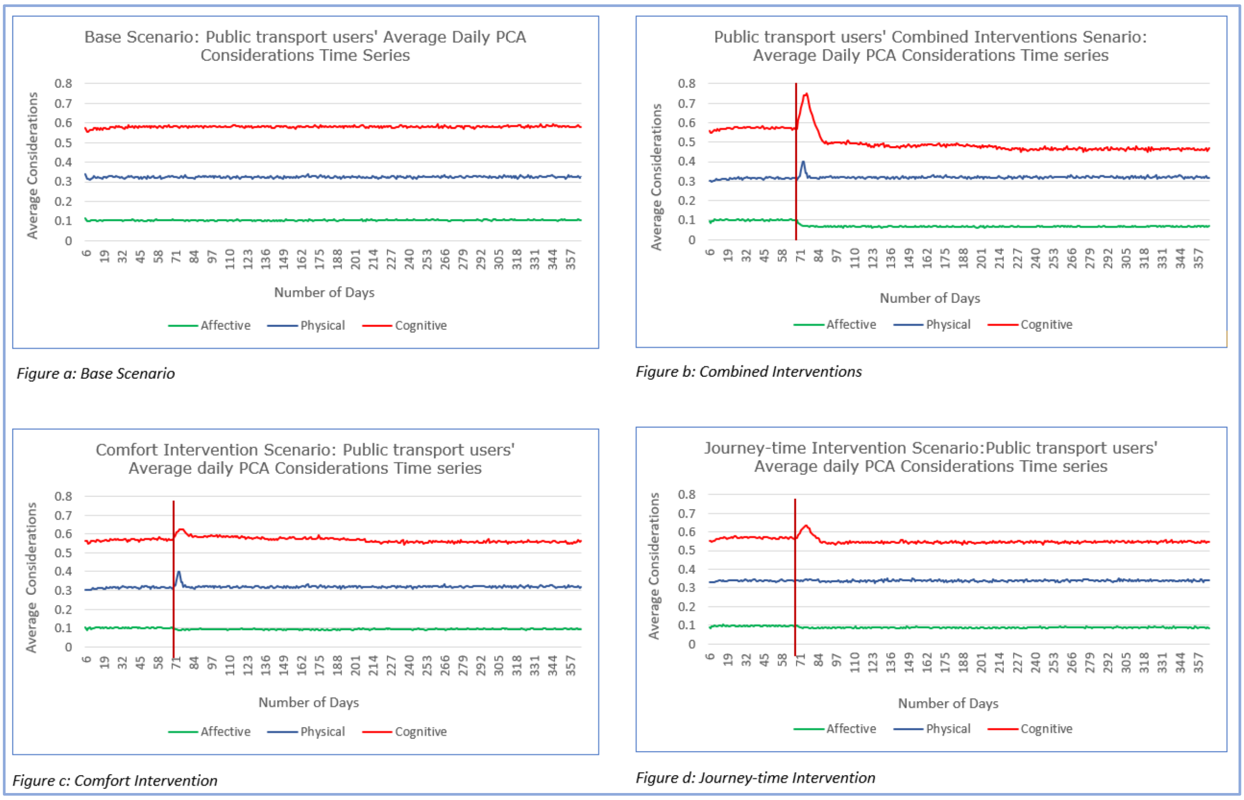

Figure 7.16: Public transport users' average daily PCA considerations

The emotional consideration of public transport takes from all the four concerns expressed, but it is the least considered in public transport users' mode choice decision process.
Figure 7.16(b) is the time series for the combined interventions. The figure shows an initial rise in the cognitive value from 0.55 to 0.75 before declined and remained at 0.49. The initial rise can be attributed to the engagement in learning about the new interventions and to evaluate its benefits. There is also a rise in the average physical considerations from day 70 until day 75 and remain steady at 0.3. The affective consideration value can be observed to have a reduction from 0.3 to 0.27, due to a reduction in the average cognitive considerations.
Figure 7.16(c) and Figure 7.16(d) are the *comfort* and *journey-time* interventions time series respectively. There is no observable reduction in the physical and affective consideration for the comfort intervention scenario. This can be attributed to the limited strategy that can be provided to alleviate public transport user concerns for comfort. The result from the journey-time intervention in Figure 7.16(d) indicates an 0.02 (i.e. 2.50%) reduction in the cognitive consideration and a corresponding reduction in the affective value due to the emotional improvement from the reduced cognitive efforts.

The observations from the three experimental scenarios are that the public transport users' concerns are interrelated such that single strategy intervention may not be good enough to stimulate travellers behaviour to adopt public transport as demonstrated in average daily satisfaction Figure 7.15 (c) and (d) and average daily PCA consideration in Figure 7.16 (c) and (d).

7.10.5 Experimentation on Pedestrians

The following are the concerns on which interventions provided for the pedestrians' population: *reliability, journey-time, comfort, safety/security* and *personal mobility*.

The three scenarios investigated are:

(1) the combined interventions involving all strategies formulated for the pedestrians.

(2) the *reliability*, *personal mobility*, and *Journey time* (three-strategy) intervention.

(3) the *comfort-security* intervention (two-strategy) intervention.

The Pedestrians' average daily satisfaction

Figure 7.17 compares the pedestrian average daily satisfaction time series.

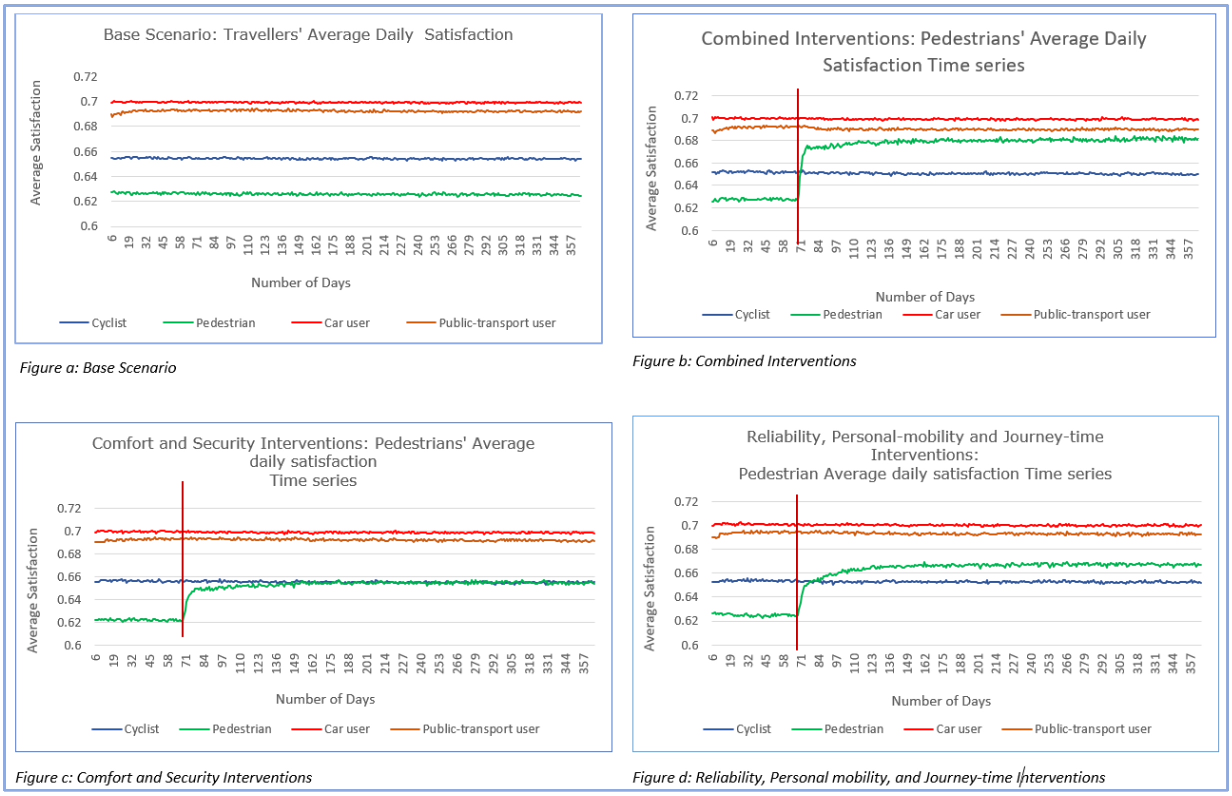

Figure a: Base Scenario

Figure b: Combined Interventions

Figure c: Comfort and Security Interventions

Figure d: Reliability, Personal mobility, and Journey-time Interventions

Figure 7.17: Pedestrian average daily satisfaction

Figure 7.17(a) is the base scenario time series. Figure 7.17(b) shows the time series for the combined interventions. Figure 7.17(c) is the series for the three-strategy intervention, while Figure 7.17(d) presents the time series for two- strategy intervention. All interventions are applied at day 70.

Comparing the four time series in Figure 7.17, it can be observed that the combined intervention in Figure 7.17(b) produces a significant improvement of 0.056 unit (i.e., 7.78%) of average daily satisfaction after the intervention. The two-strategy intervention in Figure 7.17(b) produces 0.024 unit (i.e., 3.33%), and there is an improvement of 0.037 unit (5.14%) in the three-strategy intervention. Different combinations of strategies produced different results. This is due to different classes in the pedestrian population having varying concerns that are interrelated. The scenarios indicate that pedestrians are more concerned and attached importance to the ease of *personal mobility* and *journey-time* more than the *comfort* and *security/safety*. However, one important insight from the behaviour of pedestrians is that combining related strategies show the possibilities of providing better results.

Pedestrians' physical, cognitive and affective requirements considerations

Figure 7.18 compares the pedestrians average daily PCA requirements considerations. Figure 7.18(a) is the base scenario time series which indicates that pedestrians considered most the physical efforts required by their journey to the university.

Figure 7.18: Pedestrian average daily PCA considerations

This is followed by the mental consideration to plan for the good routes that ensure a safe and good journey time. Lastly, they considered the affective aspect of their experiences regarding the ease of satisfying the needs. Figure 7.18(b) is the time series graph for the combined interventions. The three-strategy intervention time series is shown in Figure 7.18(b) and Figure 7.18(c) presents the two-strategy intervention.

From the three figures (i.e., Figure 7.18(b), (c) and (d)) the considerations on physical requirement remain relatively high and stable in all scenarios. The reason is that physical consideration is a major requirement in walking mode. However, there is an improvement of 0.04 unit (4.70%) in the level of physical consideration for the combined interventions. This can be attributed to interventions on *personal mobility* by ensuring obstruction-free walkways as well as maintenance of open edges. However, there could be elements of interdependency influence in the combined intervention as the same improvement in *physical consideration* cannot be observed in the intervention that involves the *personal-mobility* strategy (i.e., three-strategy intervention).

On the cognitive considerations, significant observable improvements can be seen in all the scenarios. The improvements can generally be attributed to reductions in the level of mental activities involved in pedestrians planning as a result of the provision of safe and obstruction-free routes.

Due to improvements in the *cognitive* and *physical* considerations, there are corresponding reductions in the level of affective consideration in each of the three scenarios. However, interventions that can improve walking environments such as *direct link routes*, closer *crossing facilities* at the regular interval and *attractive side scenes* could play an additional role in improving pedestrian experiences.

In all the scenarios for the average daily satisfaction and PCA satisfaction, it can be observed that interventions impact more on the pedestrians' cognitive involvements. Hence to achieve reasonable improvements in pedestrian journey experience, focuses should be on interventions that could reduce the mental involvement of walking mode while developing strategy and policy. One important insight into the pedestrians' concerns on walking is that there are interrelationships among the constraints such that an intervention to solve a problem can alleviate other challenges.

7.10.6 Experimentation on Car users

The effects of two intervention scenarios i.e. the *pro-car* and the *anti-car* use are investigated for the car users'. The constraints focussed in the interventions are: *reliability, journey-time, comfort, convenience, and costs and value for money*.

The two experiments are:

(1) the pro-car use interventions that provide improvements in the driving environments.
(2) the anti-car use interventions that discourage continued use of private car among the travellers to the university.

Car users' average daily satisfaction

Figure 7.19 compares the base scenario time-series with the pro-car and anti-car use intervention scenarios. Figure 7.19(a) is the base scenario time series that present the default behaviour of car users. Figure 7.19(b) is the time series for the pro-car use interventions that include intervention such as reliability in journey-time, provision of comforts and conveniences as well as improvement in value for money experiences. Figure 7.19(c) is the time series for the anti-car use interventions that focus on reducing travellers' satisfaction on the value for money (e.g., increase in the parking fare and reduction in the number of parking spaces) within the university.

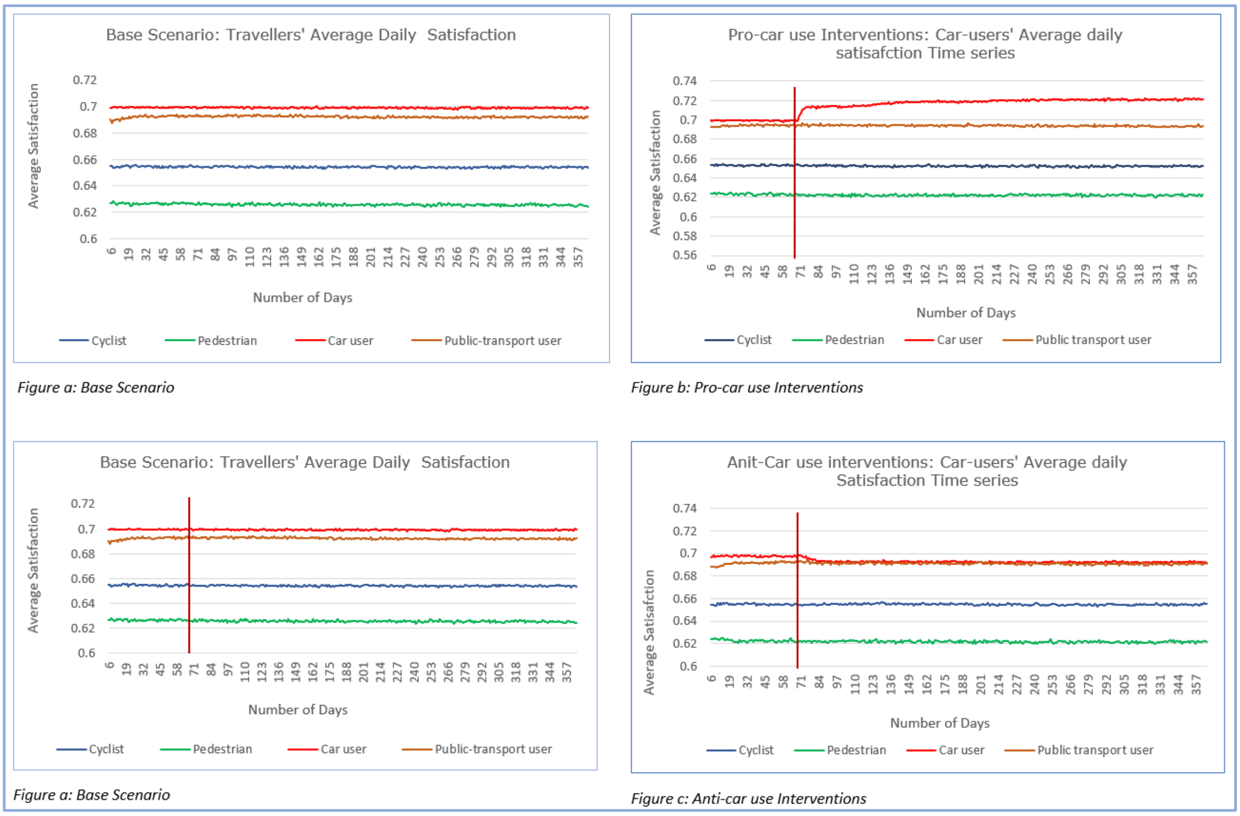

Figure a: Base Scenario

Figure b: Pro-car use Interventions

Figure a: Base Scenario

Figure c: Anti-car use Interventions

Figure 7.19: Car-users average daily satisfaction

For the pro-car use (i.e., Figure 7.19(b)) after the intervention on day 70, there is an improvement of 0.025 unit (i.e., 3.33%) in the car users' average daily satisfaction level. For the anti-car use (i.e., Figure 7.19(c)), there is an observable impact of the intervention with a decline of -0.01unit (1.33%) in the average satisfaction level. The negative value in average daily satisfaction is due to the increase in parking fee and the removal of some parking spaces in the university. These measures increase the worries of some car users on walking long distances from the available parking space to their destination within the University. Although the anti-car intervention has an observable impact on the average travellers' satisfaction, it can also be observed that in general, the average daily satisfaction remains relatively high. This can be attributed to the views of many travellers about car use, including its comfort, safety, and the symbolic affective (i.e., personality) feelings that people attached to car use.

The Car users' Physical, Cognitive and Affective requirements consideration

Figure 7.20 compares the car users' average daily PCA considerations on their journey to the university. Figure 7.20 (a) is the base scenario graph which shows that car users have high cognitive consideration due to journey planning (e.g., shorter or traffic-free routes) and planning to travel within a particular period so as to avoid traffic jams. The low level of physical consideration (i.e. 0.28) is an indication that car users worry less about physical consideration due to its automobile nature.

Figure 7.20: Car users' average daily PCA considerations

Regarding the affective consideration, car users generally do not have or have less emotional worries about their travel mode, this is due to the comfort and conveniences of the mode. The current observable level of affective consideration (i.e. 0.09) can be attributed to the emotional impact of few failed expectations experienced by car users, especially in journey time due to heavy traffic and lack of information when needed (e.g. encountering road diversion without prior awareness).

Figure 7.20(b) represents the time series for the pro-car use interventions. The time series shows improvements over time in the travellers' average daily considerations with 0.02 unit (i.e., 2.5%) improvement on the cognitive consideration, 0.06 unit (i.e. 7.5%) on the physical consideration, and a noticeable improvement in the average daily affective considerations.

In the anti-car use intervention, Figure 7.20(c), shows that the physical and affective considerations are affected. There is an increase of 0.15 unit (18.75%) in the car users' average daily physical consideration, and an increase of 0.03 unit (3.75%) in the affective consideration at the end of the simulation. The rise in the physical consideration is due to the dissatisfaction in finding a suitable car park that is closer to the destination within the campus, while the rise in affective consideration is due to dissatisfaction from all aspects including the increase in the parking fee.

7.10.1 Experimentation on Travellers' Mode Shift Pattern

Intervention on Travellers' Mode Shift Pattern

Two sets of scenarios are observed on the mode shift behaviour of travellers: (a) interventions that exclude car users, and (b) interventions that include all travel modes.

(a) **Interventions that exclude Car users**

Figure 7.21 shows the travellers' mode shift adoption pattern that excludes car users. In this experiment, all the seven categories of strategies are applied to cyclists, public transport users, and pedestrians.

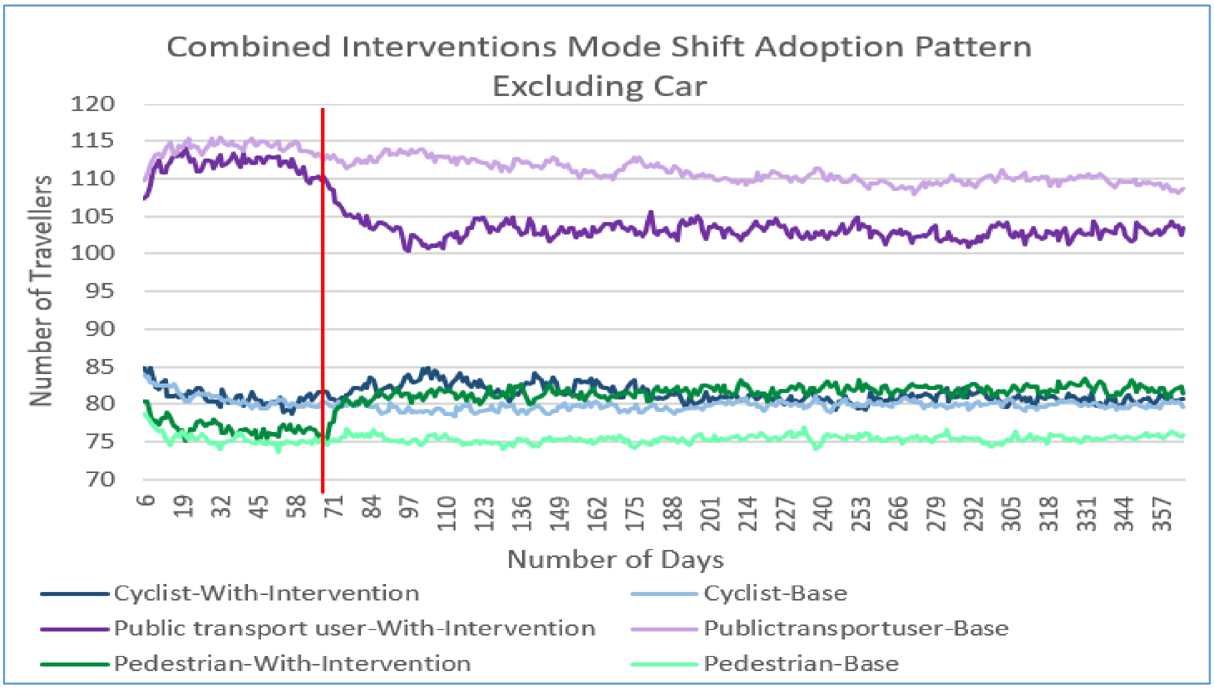

Figure 7.21: Travellers' Mode shift adoption pattern Excluding Car users

The interventions stimulate some of the travellers to shift mode to walking. There is a gradual increase in the number of pedestrians from 75 to 82 and the shift remains steady until the end of the simulation. The increase of 7.70% in the number of pedestrians' shows that a number of other travel mode users are attracted by the current improvement in the walking mode. The remaining potential pedestrians among other traveller groups are restricted by factors such as not residing within walking distance. For the cyclist's group, there is an initial increase of 6.30% in the cyclist's number after the intervention. The increase reached a peak at day 102 before it declines to the initial setup value of 82 cyclists after 115 days of intervention. The reason for the initial increase was as a result of social interactions between potential cyclists who are aware of the new improvements in the cycling environment and the regular cyclists. The reduction in the number of cyclists after day 102 can be attributed to the behaviours of new adopters who after cycle for some days considered cycling not as satisfied as their previous travel modes. In addition, it could be that the concerns of certain groups within the cyclists' population are not addressed or that the level of interventions provided to address the respective concerns did not meet the satisfaction threshold of the new adopters. This 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. Regarding the shift in the public transport users' category, there is 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 due to the average distance they cover. However, the reduction of 8.7% in the proportion of public transport users after interventions indicates that some of the travellers (i.e., public transport users) who are living within cycling and walking distance have adopted the two travel modes.

The insight from this scenario (i.e., the intervention that excludes car users) is that in order to ensure the sustainability of adoption behaviours among new travellers, the measure of intervention provided to address a concern should be adequate.

(b) **Interventions that include all travel modes**

In this experiment, all seven categories of interventions are applied to the entire traveller population, including car users. Figure 7.22 presents the effect of the combined interventions on the travellers' mode shift. Measures that are peculiar to car users', such as removal or addition of parking space and an increase in parking fee are included.

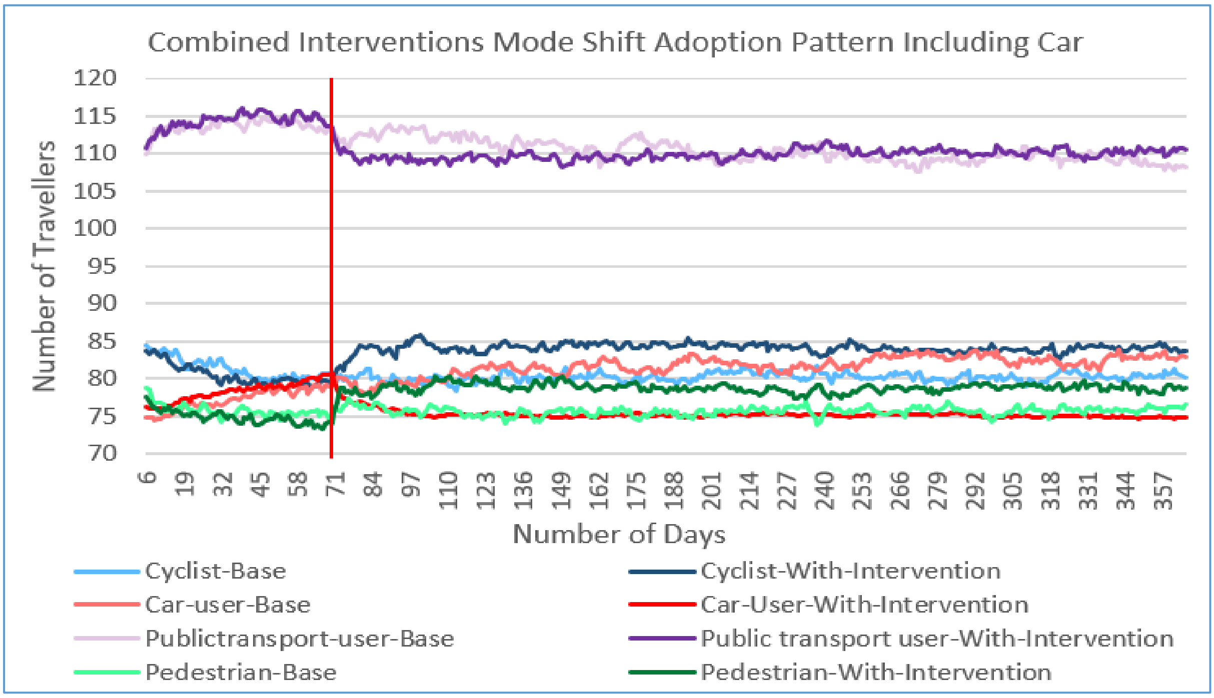

Figure 7.22: Travellers' Mode shift adoption pattern Including Car users

Figure 7.22 indicates that there is a 12% reduction in the number of car users to the university. This implies that a certain proportion of car users has shifted mode usage to other travel modes that satisfy their needs due to the increase in the parking fee and removal of parking spaces within the university.
For the cyclists, there is an increase of 6.3% in the proportion of cyclists to the University; the same proportion that was recorded at the early stage of the scenario without car users (i.e.

Figure 7.21). However, in this scenario, the proportion is sustained until the end of the simulation. One reason for this behaviour of cyclists is the reduction in the number of car users on the road to the university, which encourage cyclists to continue using the mode. Furthermore, the fact that the proportion recorded (i.e., 6.3%) is the peak of mode shift to cycle in both cases is a clear indication that cycle ownership (i.e., access to bicycle) is an important factor considered by other travel mode users to adopt cycling. There are indications that if conditions that encourage cyclists can be put in place and sustained, there is a likelihood of more travellers acquiring a bicycle for their journey to the university.

On the public transport users, the observable behaviour is that pedestrians and car users who do not own a bicycle or do not reside within a cycling distance as well as car users who are dissatisfied with the new parking fee policy adopted public transport. Even though, 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 (Figure 7.21). This can be attributed to some pedestrians who are potential cyclists but who prefer walking to cycling because of the attitudes of some car users. The proportion of travellers that accounted for the difference between the two scenarios are those that 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. From the experiments, it can be observed that interventions to car travel environment make a significant difference in the behaviour of all other mode users to the University. Also, some of the car users' daily distance travels are within the cycle and public transport travel range. However, switching mode might not be practically possible for some car users, especially those who come to the university from the neighbouring cities and those who are emotionally tied to car use.

Insights from the interventions that include car users are that some car users can switch mode if other travel modes services are made better even without imposing further charges. Another insight is that 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.

7.11 Recommendation for Policymaker on the use of MOSH Methodology

The results of different interventions targeted at various categories of travellers explain the need to understand the influence of travel requirements on traveller's choice of mode. The study provides a basis for explanations of the contributions of travel requirements on the decision of a traveller, and the levels of contributions. It also shows that changes in the physical environment drive travellers' mode choice pattern.

As demonstrated in the public transport user's intervention scenario in Figure 7.15 and Figure 7.16 where the combined intervention scenario produced better results than the two single intervention scenarios on both the average daily satisfaction and the average daily PCA considerations. The proportion of the population that is affected by a constraint and the hidden interdependency among system components are the important factors that need to be understood and considered for intervention by the policymakers as demonstrated in the scenarios in Figures 7.15 (c) and (d) and Figures 7.16 (c) and (d). Therefore, policymakers need to identify (e.g., through sensitivity analysis) the constraints that have relationships and that produce much influence on travellers' behaviours. Such components could be explored to achieve more gains through interventions.

Furthermore, policymakers must understand individual groups within the population of traveller so as to define the appropriate strategy to stimulate the behaviour of travellers in the group better. This includes identifying the constraints or concerns that are important to different groups of travellers. For instance, Figure 7.13(c) and (d) show that two-strategy interventions to cyclists' population produced more satisfaction impact than the three-strategy interventions. The reason is that the intervention was targeted at the population of cyclists that have much concern about the problem the intervention addresses.

When the appropriate measure is taken by the policymaker, funds, time and resources will be saved on interventions provisions and there will be a significant impact on the target population.

7.12 Reflection on Applying the MOSH Methodology

The use of MOSH methodology in this case study has demonstrated its capability to model problems at the disaggregated level in order to understand groups within a population. The MOSH methodology integrates CWA, CMA, Fuzzy sets into ABM to investigate individual travellers' response to travel requirements.

The inclusion of the *Fuzzy Collection package* into the methodology's modelling process offers the support to identify the contributions of each decision variables to travellers' mode choice. The *decomposition algorithm* in the Fuzzy Collection package provides the mean of identifying the contribution of decision factors to travellers' decision as well as the importance attached to decision variables by a traveller. For instance, in all the scenarios that involved the average daily satisfaction and the average daily PCA satisfaction in this case study, it is demonstrated that the contributions made by each of the travel requirements to travellers' decisions are evaluated. In Figures 7.13 (b, c, and d), it was possible to identify that cyclist attached more importance to their safety and comfort than the journey-time and conveniences. Also, cyclists have greater considerations for the cognitive travel requirement as a result of their safety concerns (Figure 7.14). The two findings affirm Wardman *et al.* (2001) opinion on the varying impact of travel requirements on travellers and that certain considerations among the travel requirements are paramount to individual travellers in their decision making. These features of MOSH methodology are currently not present in any of the existing agent-based development frameworks.

Another strength of MOSH methodology is in its ability to investigate how both ergonomics and psychological strategies influence travellers' decisions and investigate the relationship between the strategies from the two domains. For instance, Figures 7.14 (c and d) show that travellers' respond faster to intervention from the ergonomics strategy than to the psychological strategy. However, HF' experts including (Stanton et al., 2013) and Transport Psychologists experts such as (Mann & Abraham, 2006 and Gardner & Abraham, 2007) had at different times investigate factors that influence travellers' decisions in transport system separately without finding the relationships that exist among the factors.

Furthermore, the ability to generate affective display value (i.e., emotional perception) directly from the survey data (Algorithm 5.1) as the traveller traverse the travel environment is one of the strengths in MOSH methodology that is applied in this study. The MOSH framework as part of the methodology includes the CWA that provides a means to analyse and capture travellers' perception at various stage of their journey in the transport system.

Lastly, the combinations of many established tools in the methodology provided mechanisms for easy identification of appropriate strategy and policy that give optimum results. However, this feature also contributes to difficulty in its usage.

7.13 Limitations of the MOSH Toolkit Applicability for this Case

The MOSH toolkit includes the MOSH framework and the MOSH methodology. The major limitation observed from the application of the MOSH toolkit in the case studies come from the difficulties in mastering the use of some domain-specific tools such as CWA and CMA that form the components of the toolkit. Another limitation of the MOSH methodology in modelling modal shift problems is the lack of capacity to put in place the resources and infrastructure to support travellers in the affected areas of the transport system. For example, building infrastructures such as walkways and cycle routes and installation of pedestrian crossings is beyond the capacity of the researcher. Formulation of policies that will be respected across the population of travellers could only be put in place by the County (policymaker). In view of the limitations, it is difficult to conduct post-intervention investigations. Notwithstanding the limitations, measurable units have been used to represent perceptions from the interventions, which are compared with the base scenario as validation (result validation) Law (2008), so as to gain an understanding of the impact of interventions on the target audience. Lastly, the limitation on the capacity of the development software i.e., Repast is observed in generating high graphics output.

7.14 Conclusions on the MOSH Applicability for this Case

The case study discussed in this chapter has demonstrated the applicability and effectiveness of MOSH methodology in studying and understanding the attributes of individual travellers. It also demonstrated how the heterogeneity in travellers' features can be explored to effectively stimulate their behaviour toward adopting other travel modes.

In this case study, the following set of working hypotheses have been examined:

- Hypothesis 1: **Levels of physical, cognitive and affective considerations impact on travellers' travel mode satisfaction**. The outcomes of the intervention scenarios demonstrated that the travel requirements (i.e., PCA) considerations in journey making have roles to play in travellers' decision-making. The scenarios in (Figure 7.14;

Figure 7.16; Figure 7.18 and Figure 7.20) that show various travellers' behaviours in PCA considerations in response to interventions have proven that the hypothesis can be accepted.

- Hypothesis 2: **Interventions on travel system's reliability, comfort, safety, convenience, journey-time, personal-mobility and value for money constraints influence travellers' physical, cognitive and affective considerations**. The outcomes of the intervention scenarios carried out on the travel environment showed that improvements in the ergonomics and psychological factors impact on the travellers' average daily satisfaction and influence their mode choice behaviours. These are demonstrated in Figure 7.13 for the cyclists' population; Figure 7.15 for the public transport users' population. Also, in Figure 7.17 for pedestrians and car user population shown in Figure 7.19. The results from the experiments have proven that the hypothesis is good enough to be accepted.
- Hypothesis 3: **Understanding individuals or group of travellers' abilities regarding their physical, cognitive and affective considerations assist in stimulating their behaviours.** The accurate representations of individual perceptions in the system with the use of MOSH CWA and CMA components; as well as the stereotypic learning of groups within a category of travellers' population provide adequate information and details that distinguish individuals regarding their features and abilities. This understanding is demonstrated in Figure 7.14; Figure 7.16; Figure 7.18 and Figure 7.20, hence, the hypothesis can be accepted.
- Hypothesis 4: **Interventions on reliability, comfort, convenience, journey-time, safety, personal mobility and value for money constraints of travel system influence travellers' mode shift behaviour.** The interventions provided in the scenario that excludes car users and the scenario that includes car users (Figures 7.21 and 7.22 respectively) demonstrated the interplay that occurs in the physical environment as travellers interact and shift travel modes usage from one mode to the other. The outcomes of these experiments prove that the hypothesis can be accepted.

7.15 Summary of Study

The case study discussed in this chapter is with the intention to check the effectiveness of the methodology in supporting the understanding of individuals' attributes as it affects travellers' behaviours in travel mode choice. It also demonstrated how the understanding of individuals can support the formulation of the best strategy and policy for interventions that can be used to stimulate travellers' behaviours for modal shift. The study involves a set of travellers using various travel modes including public transport, cycling, walking and private cars to the University of Nottingham. The methodology process map (Chapter 5) was followed in modelling the problem area.

Insights into the travellers' concerns and PCA considerations regarding their travel experiences to the university were gained through focus group meetings and interviews. The concepts of the transport systems to be investigated and the needs of the travellers were identified during these meetings. The travellers' needs and the transport system concepts to use in the project are viewed and described from the perspective of HF and PSY. The process provides a ground for common terms to be defined among collaborators and use throughout the case study. The process is also a step to ensure easy communication among members of the team that is involved. The needs of the travellers have been defined as *efficient*, *safe* and *comfortable* travel mode to and from the university. Seven measurable terms were also defined as the criteria with which travellers can evaluate the performance of their modes.

A questionnaire method that contains investigative questions was used during the data collection process. Moreover, analytic processes included in the MOSH methodology such as the CWA AH's means-end links and CAT are employed to analyse interdependency among the transport system's components. In addition, a statistical clustering algorithm was used to identify various groups in travellers' population that have distinct features. Travellers' concerns and the corresponding suggested solutions were used to formulate policies and develop strategies for interventions regarding various areas of concerns expressed by the travellers. Four sets of experiments were conducted on each of the four traveller categories (i.e., public transport users, car users, pedestrians and cyclists) in the following areas: (1) travellers' average daily satisfaction. (2) travellers' average daily PCA considerations that demonstrated the impact of travel requirements on the travellers' decision, and the (3) travellers' mode adoption pattern in response to the policy interventions.

In all the experiments, the base scenario and three different interventions were contrasted for the pedestrians, cyclists and public transport users. The three interventions included the one that involves the application of combined interventions to all identified concerns; and two experiments that involved other different combinations as informed by the result of the classification analyses. Two interventions (pro-car and anti-car user) were provided for car users categories; while interventions that focus on investigating modal shift pattern among travellers are also applied.

On the travellers' average daily satisfaction, observations from the graphs indicate that certain individuals or group of individuals are sensitive to an intervention or combined interventions than others. The reason is due to the importance attached to the concerns or constraints that such interventions address on one hand and the number of affected individuals within the population on the other hands. Furthermore, the average daily PCA considerations interventions for all categories of traveller show that the reductions on the levels of average daily PCA consideration are proportional to increase in the average daily satisfaction of travellers across various travel modes as shown in all graphs that represent average daily satisfaction and average daily PCA considerations.

The outcome of the study especially on the PCA considerations affirms the (Wardman *et al.,* 2001) opinion that PCA considerations are part of the requirements that need to be satisfied in order to make a journey and are the factors that shape travellers behaviours in mode choice. The study also affirms Mann and Abraham (2006) submissions that the considerations affect individuals and group of individuals differently.

8 Conclusions

This chapter presents the summary and evaluates the research. It reiterates the purpose and the use of MOSH methodology as well as areas of future work. Section 8.1 summarises the research. A review of the purpose and uses of the MOSH methodology is presented in Section 8.2. Section 8.3 evaluates the fulfilment of the aim and objectives of the research. The contributions made throughout this research to fulfil the research gaps are reviewed in Section 8.4. Section 8.5 discusses the limitations of the study and the proposition for future research. The concluding remarks are presented in Section 8.6.

8.1 Summary of Research

The research in this thesis explores the potential of SE practices, tools and methods with AI techniques to incorporate HF and PSY knowledge in a structured approach into the ABM paradigm. The research work is motivated by the need to understand travellers behaviours and the factors that influence their decisions in transport systems while choosing their travel modes. Experts in the domain of PSY are interested in the relationships between psychological processes (factors) and peoples' behaviours. While HF' experts are concerned with the study of factors and the development of tools that improve users' experiences. By bringing together the two domain practices, the research aimed at providing a novel methodology that allows stakeholders to use HF and PSY knowledge better in investigating travellers' mode choice decision in the transport system. It also provides a structured and standard platform for collaboration among stakeholders.

In order to fulfil its aim, the research is guided by four questions:

- How can Computer Science practices and methods assist stakeholders (experts and modellers from other disciplines) to apply HF and PSY knowledge better in modelling modal shift in travellers' mode choice?
- How can Computer Science practices and methods assist stakeholders to build models that answer specific modal shift questions in transport systems?
- To what extent can SE and AI methods and tools assist in the development of a methodology that provides a collaborative platform for experts from different backgrounds?
- How can ABM paradigm coupled with SE practices and AI techniques assist stakeholders to gain insights into understanding travellers' decision-making factors in travel mode choice?

To answer the research questions, the methodology includes a development framework to conceptualise the travellers' mode choice process in the transport system. It works with the idea that it can be difficult to change people's attitude, but it is easier to change the environments in which people operate.
The first research question is answered with the incorporation into the framework, the CWA, an HF analytic method that is used to capture the dynamics of travellers as they traverse the transport system environment and provide insight into the constraints imposed by the system on their operations. Also, the inclusion of CMA which provides supports for capturing

travellers' emotional perceptions at various stage of their journey. The second question is answered by following the methodology process map in Chapter 5 and demonstrated in the case study Chapters 6 and 7 of this thesis. The third research question is addressed with the use of SE UML as the standard language specification for easy communication among collaborators as demonstrated in the case study chapters. The fourth research question is answered with the outcome and lesson learnt from case study 2 that investigated the significance and contributions of the travellers' decision factors to their decisions.

The in-depth evaluation of the aim of the research is carried out by investigating the effectiveness and the credibility of the MOSH methodology with two travellers' mode choice studies:

1) The study first involves stimulating a modal shift from motorised travel modes to non-motorised travel. This study focuses on the formulation of policy and development of strategy as interventions to stimulate travellers' behaviours in the transport system.
2) The second is on understanding travellers and their responses to decision factors; this involved a real-world implementation of understanding personality and factors that influence individual behaviours.

The two case studies provide insights into various aspects of complex transport systems design that involve interactions between travellers and the transport system's resources.

8.2 Uses and Evaluation of the MOSH Methodology

This section reiterates the purpose of the MOSH Toolkit (i.e., the framework/Methodology) and evaluates the influence of Computer Science tools and practices used in the development of the methodology. The tools and practices include SE practices and UML as the standard language adopted with the components such as the CMA, CWA and Fuzzy that make up the methodology.

8.2.1 Purposes and General Uses

The main purposes of the MOSH methodology are:

a. To enable better usage of relevant HF and PSY knowledge in modelling travellers' behaviours in travel mode choice.
b. To serve as a platform to promote collaborative work among modellers from different domains. By following the procedures provided in the methodology process map, a modeller can work as an individual or work within a group to investigate factors that influence travellers' decisions.

In terms of uses, the MOSH methodology is designed with the flexibility to allow relevant tools to be incorporated at various stages and especially in areas that have specific problem context, and different scenarios to be modelled. For example, in the knowledge gathering process, a suitable data gathering method could be employed to gain an in-depth understanding of a domain. However, the design of data collection materials (e.g., questionnaires) should follow the format discussed in the thesis (Section 5.3.1).

The basic UML templates for the systems' components are designed to be adapted and extended for a specific purpose. This is demonstrated in the use cases and the traveller agent class diagram in case study 1 (chapter 6) and case study 2 (chapter 7). Also, in the evaluation of traveller's decision-making process, modellers have the flexibility of using different techniques suitable for the situation being modelled depending on the nature of uncertainty within the problem area and the frequency at which the evaluation is to be made. For instance, the use of *utility functions* is a suitable method to evaluate decision that does not involve observations over a period, while the *moving average* function is suited to get the overall idea of the users' perceptions over a period of time. This is demonstrated in case study 1 (Chapter 6) that relies on Cobb-Douglas utility functions to evaluate decision factors while case study 2 (Chapter7) employed the utility function and the decomposition algorithm to determine the influence of variability in individuals' abilities on their perceptions.

8.2.2 Evaluation of the MOSH Methodology

The incorporation of HF and PSY knowledge in the Methodology is with the intention to analyse and measure travellers' perceptions regarding their needs as they traverse the dynamic transport system, and to capture travellers' emotional state at different stages of their journeys. However, due to the complexity of the transport system's including its unpredictable fashion in behaviour and interactions, the need for SE principle of *separation of concerns*, *extensibility*, and *reusability* becomes necessary. SE as an established technique has been developed by computer scientists and software engineers for many years to fulfil similar needs for software projects.

One of the practices of SE is object orientation in the analysis and the design of a complex system. The practice allows the key SE principle of *separation of concern* to be incorporated as part of the MOSH methodology in conceptualising travellers decision-making process in mode choice. The MOSH methodology design is with separate classes for *Agent* and *Opportunity*, with overlaps in the aspect of the *Opportunity's* attributes (e.g. travel mode attributes) to be consumed by the *Agent* (travellers). This modular practice reduces the complex system into a series of manageable components. It also promotes the ease of maintaining the system. The broken of the system into layers and components with specific responsibilities improve the *extensibility* of the system. With the independence of the components connected by an abstraction layer, adding new capabilities and incorporating new features become easy. This feature was applied in case study 2 where the fine-grain level of details taken in understanding individuals require an additional class to be created to implements the travellers' perception for that new level of responsibility. Since each component addresses a separate concern, it improves the *reusabilit*y of the methodology. For example, the MOSH methodology decision module is reused in its entirety for the two case studies in this thesis, and hence, it reduces development time and cost.

The UML as the Standard language notations adopted in the MOSH methodology design is with the intention to serve as the communication standard among collaborators. It has records of applications in visual representations of OO designs that are not programming language-specific. The system's structure, traveller's behaviour, and processes description with the UML facilitate better communication among collaborators and a bridge between disciplines. It also provides design documentation as a co-product in the methodology in addition to information about design architecture. The purpose of UML usage is demonstrated in the two case studies described in Chapters 6 and 7. The use case and class diagram templates of the methodology were adapted with the addition of new use cases and internal properties that suit each specific problem. The experience and findings indicate that using the UML in the modelling process promote effectiveness in the communication of ideas and promote clarity through documentation.

Furthermore, the evaluation of MOSH toolkit components including Fuzzy sets, CMA, CWA and ABM is as follows:

The incorporation of Fuzzy sets as an integral component of the MOSH methodology provides a means of evaluating imprecision and uncertainty in problems. First, its uses with the CMA determines the travellers' emotional state at various stages of their journey. This is explained in Algorithm 5.1 and evaluated in Section 7.6.1 for the *derivation of travellers' affective display perception from the survey data* in case study 2. Also, the fuzzy sets technique is used in the unbundled the composition of travellers' decisions into their constituent parts with their strength as explained in the *decomposition algorithm* (Algorithm 7.1) and evaluated in chapter 7 Section 7.8.2 to determine the travellers' PCA considerations. These features of the methodology are also evaluated in all the scenarios that involved the average daily satisfaction and the average daily PCA satisfaction in chapter 7

The CWA in the MOSH framework provides a means to analyse the travellers' situation (temporal and spatial) at various stages of their journey in the transport system. The CWA-AH provides the toolkit with modelling capability to reveal the interdependencies among the transport system's constraints. This makes possible the application of a single intervention to resolve issues related to many system's constraints. This MOSH capability is evaluated in the two case studies reported in this thesis. For instance, in Section 6.10.3.2, the obstruction-free routes and maintenance of walkways interventions were to address journey-time consideration in Figure 6.13 (b); due to the interdependency in the constraints, the intervention contributed to the resolution of the travellers' safety and convenience constraints to some extent. In addition, one emerging novelty of the methodology is its ability to reveal the relationship between ergonomics and psychological strategies and how they affect travellers' decisions. This is demonstrated in the case studies. For instance, Figures 7.14 (c and d) show that travellers' respond faster to intervention from the ergonomics strategy than to the psychological strategy. However, HF' experts including (Stanton *et al.*, 2013) and Transport

Lastly, the justification for the ABM paradigm as part of the MOSH methodology modelling process is evaluated throughout the experimentation of the two case studies reported in this thesis. The experimentations in Section 6.10.1, Figures 6.12, 6.14 and 6.16 showed travellers' interactions during information seeking (cognitive processing) that include travellers' engaging in imitating and inquiring behaviour from one another. Also, Section 7.10.1 presents travellers' mode adoption pattern as a result of interactions among them in response to interventions.

8.3 Evaluation of Aim and Objectives

The thesis aimed to develop a novel modal shift methodology with SE tools and methods together with AI techniques to incorporate HF and PSY knowledge into ABM. The intention is to supports stakeholders with a methodology that allows domain knowledge to be embedded into the modelling process in a structured way. To achieve the aim, five research objectives were identified in Section 1.2. The objectives are evaluated as follows:

Objective 1: Review of related literature to understand requirements for travellers' mode choice process and identify gaps (if any) in the existing methodologies. The first objective was fulfilled by identifying the limitations in the existing methodologies for modelling behaviour change of dynamic travellers in the transport system and identify potentially relevant tools and methods that can assist in achieving the aim of the research.

Objective 2: Construct a development framework to conceptualise travellers' mode choice process through the knowledge gathered from the initial survey. The second objective was accomplished with the development of the MOSH framework in Chapter 4.

Objective 3: Apply SE tools and methods and AI techniques in designing the template for the key components of the system. The third objective was achieved with analysis of travellers' mode choice processes following the OOA requirements engineering as well as designing the structure of the major components using the UML notations described in Section 5.3.2. The use of the fuzzy sets is in the development of *Affective display generation* and *decision factors decomposition modules'* template for modelling travellers' emotional states.

Objective 4: Develop the methodology process map. The fourth objective was achieved with the development and description of the MOSH methodology process map in Chapter 5. The description includes how to use various aspects of MOSH including aspects that are reusable (generic) and those that have specific applications in the areas being investigated.

Objective 5: To validate, verify and evaluate the effectiveness of the methodology with case studies from the transport systems. To meet the fifth objective, two case studies that involve the application of the methodology in the strategic policy formulation, and in the understanding of factors that determine travellers' decisions were carried out. The studies demonstrated the credibility and effectiveness of the methodology in different situations.

Consequently, the aim of this research has been fulfilled, by achieving the above-stated objectives.

8.4 Contribution to Knowledge

The main contribution of this research to knowledge emerges from the development of MOSH methodology. A new methodology with a framework that defines a novel way of representing HF and PSY knowledge within social simulation studies with the help of Computer Science tools and methods, as well as providing access to Computer Science techniques. For the first time, this research combines knowledge from two principal disciplines (i.e. HF and PSY) with Computer Science practice including SE, AI and Data Science to address personality, uncertainty and other system factors (e.g. interdependent components) that determine travellers' decisions in mode choice.

The specific contributions to knowledge, all in the context of modelling mode choice for travellers, include:

1) the MOSH framework, supporting the model development of social simulation models;
2) the MOSH methodology, structuring the study life cycle process flow, data flow, and information flow;
3) a novel algorithm for generating traveller's emotional state (affective display) from the survey data; and
4) a novel algorithm for the decomposition of travellers' decision into their constituent parts with the capacity to identify the significance of each constituent part.

8.5 Limitations of the Study and Future Work

Social simulation studies are theory-guided and are generally more useful to support decisions on policies. One fundamental limitation of social simulation models is the validation process using statistical data. Experts including Sun (2006), Gilbert & Troitzsch (2005) and Jager & Janssen (2012) have identified the complications in this aspect due to the level of fieldwork required as well as parameterisation issues. Notwithstanding the fundamental limitations, the results of the case studies as demonstrated in chapters 6 and 7 are good enough to be used for policy formulation and for the development of explanations to make our environment better, rather than for accurate prediction of specific outcomes (Gilbert and Troitzsch, 2005). However, in the future, there should be a more rigorous validation process using statistical data.

Another potential limitation of the MOSH methodology is in its composition of many components which transform to the complexity of its usage. The MOSH methodology incorporated many well-established methods, approaches and models from different domains into ABM paradigm. The many parts of MOSH and the different processes involved in using these parts require expertise, which can initially be difficult for new users who are also non-experts from any of the included domain. However, this limitation could be initially overcome with the guidance of experts from the included domain (e.g. HF expert) who could be part of the project team. In addition, there could be an initial need for facilitators to provide start-up support as well as active online support for interested users. To support widespread use of the methodology in the future, the complexity needs to be reviewed and its composition be more simplified.

The methodology's core libraries are currently bound to a specific programming language. For instance, the *affective generator* algorithm and *decision factors decoupling* algorithm are all implemented in JAVA based REPAST Simphony environment. In the future, the methodology should be implemented in multiple programming languages such as Python and C# to support the widespread use as well as to validate the independency of simulation software. In addition, the methodology's adaptive learning mechanisms that currently use *similarity* for peer selection could include the use of other techniques such as *Genetic Algorithms* to provide more quality solution even with less computational time.

At present, the methodology focuses on the cases in the transport domain; the research has the potential to be extended to other areas of social systems where people's behaviour in choice-making from alternative brands that serve the same functional purpose has the potential to create challenges. In the future, the use of the methodology can be extended to other domains including education, health, business and politics where the modal shift can be experienced.

For instance, in health care delivery, it has been reported in several studies including (Pichlhofer and Maier, 2015; Oladejo et al. 2015;) that people prefer to attend secondary and tertiary health facilities while the other arms of health care services receive low patronage. A large percentage of visits to this higher arm of health care delivery are for mild ailments that can be treated at primary health facilities. Also, in the educational system, especially in developing countries, students have preferences for some professions and educational qualifications. In Nigeria for example, there has been a surge in the numbers of High School graduates seeking admissions into the University contrary to government expectations for technical oriented skills (Clark and Ausukuya, 2016; WENR, 2017). The situation has resulted in challenges of overstretching the Universities' infrastructure and added pressure on the workers. It has also led to yearly low intakes into other institutions such as Polytechnics and Colleges of Education that provide special and technical skills. Another potential new area of future research is in the marketing domain. The research idea was founded on basic marketing principles. In the future, the work can be extended to include relevant marketing strategies that can improve the research.

8.6 Concluding remarks

In conclusion, the research reported in this thesis provides a unique way of using simulation in a safe environment for testing interventions without having ethical issues and without interfering with the real systems. We take the position that the research provides an ethical way of stimulating change in human behaviour using travellers' mode choice in the transport domain as examples to demonstrate in contrary to unethical practices of accessing peoples' data in order to stimulate their behaviour without their consent. A way to help modellers to incorporate domain-specific knowledge into the modelling process while engaging in collaborations.

Furthermore, we are sufficiently satisfied with the outcome of this research. From the point of view of the framework and the methodology that form the products of the research, the case studies conducted have demonstrated that the research has provided solutions to the challenges of non-collaborative support among experts from different domains. We hope that our contributions in this regard will have a positive impact on the transport sector and other related areas, where they could be applied in the future. We also hope that experts in HF and PSY domains will find the outcome of this research useful in their research.

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Appendix A: Non-Motorised (Active) Transport Questionnaire

Active Transport Questionnaire

Introduction

In this questionnaire, you will be asked to answer some questions regarding s*hort distance journey*s (e.g. getting to the grocery store) by employing *transport means that demand physical efforts (active travel)*, such as walking, cycling and travelling by scooter. Given the health benefits of active travel, we want to understand public views on active transport environment regarding safety and comfort. We also want to assess how those views impact on your decision to walk, cycle, or travel by other means for short-distance journeys within Nottingham. The purpose is to understand current perceptions on active transport environment and develop strategies to improve the adoption of active travel on short distance journeys.

Task Instruction: The questionnaire consists of three sections:

- Section A: General information.
- Section B: Users' perception on active transport environment
- Section C: Non-active transport users.

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: What is your age: _ _ _ _ _ _ _ _ _ _ _ _ _

Q3: Do you own or have access to a car or motorbike?

☐ Yes ☐ No

Q4: What is your usual travel mode for short-distance journey? (**Tick all that apply**)

☐ Private Car ☐ Public Transport ☐ Others

☐ Walking ☐ Cycling

Q5: Do you usually walk or cycle on your short distance journey?

☐ Yes ☐ No

Note: If you have answered 'YES' to question 5, continue to the end of Section B; if you answered 'NO' move to Section C.

Q6: How often do you walk or cycle on your short distance journeys?

☐ Every day ☐ Once or twice a week

☐ 3 or more times a week ☐ Less often

Q7: What is your usual active travel mode? (walking, cycling, travelling by scooter/skateboard, etc.)

☐ Walking ☐ Travelling by scooter ☐ Others

☐ Cycling ☐ Travelling by Skateboard

Q8: What distance do you consider feasible for walking?

☐ 0 -1 mile

☐ 0-2 miles

☐ 0-3 miles

☐ Between 3 and 5 miles

Q9: What distance do you consider feasible for travelling with Scooter/Skateboard?

☐ 0 -1 mile

☐ 0-2 miles

☐ 0-3 miles

☐ Between 3 and 5 miles

Q10: What distance do you consider feasible for cycling?

☐ 0 -1 mile

☐ 0-2 miles

☐ 0-3 miles

☐ 0-4 miles

☐ 0-5 miles

☐ Between 5 and 10 miles

Q11: For which of the following journey purposes do you make with active travel? **(Tick all that apply)**

☐ Shopping

☐ Work

☐ Getting to travel mode stop

☐ Religion activities

☐ Education

☐ Others, e.g. Leisure

SECTION B: USERS' PERCEPTION OF ACTIVE TRANSPORT ENVIRONMENT.

The following questions focus on your perception of the quality of active transport facilities within Nottingham. Tick the appropriate response.

12. How satisfied are you with the following?

	Very Unsatisfied	***Somewhat Unsatisfied***	***Neither Satisfied Nor Unsatisfied***	***Somewhat Satisfied***	***Very Satisfied***
a. Sidewalks /Cycle paths/Footpaths etc.	○	○	○	○	○
b. Crossing and road signs at junctions	○	○	○	○	○
c. Attitude of other road users	○	○	○	○	○
d. Routes availability and obstruction free routes.	○	○	○	○	○
e. Shower and other facilities at the destination	○	○	○	○	○
f. Journey time consideration	○	○	○	○	○
g. Capability for luggage carrier	○	○	○	○	○

13. If you are dissatisfied with any of the items in question 12, please state the reason why and suggest solutions to the problem. (*Respond with short comments.)*

	Reason(s) for being dissatisfied	***Suggested changes that could be made to improve the situation***
a. Sidewalk ways /Cycle paths/Footpaths etc.		
b. Crossing and road signs at junctions		
c. Attitude of other road users		
d. Routes availability and Obstruction free routes.		
e. Shower and other facilities at the destination		
f. Journey time consideration		
g. Capability for luggage carrier		

SECTION C: NON-ACTIVE TRANSPORT USERS

This section is to be answered by anyone who uses travel mode other than walking, cycling, skating or scooter for short distance journeys.

Note: *Active living is a way of integrating physical activity into daily routines. NHS recommends at least 30 minutes of exercise a day, walking, cycling, skating and scooter are among the possible means of achieving active living)*

14. How do you achieve the NHS recommended daily active living? _

15. Do any of the following discourage you from walking or cycling on short distance journey? (Tick all that apply)

	Reason(s) for being discouraged	***Suggested solutions to improve the situation***
☐ a. Sidewalk ways /Cycle paths/Footpaths etc.		
☐ b. Crossing and road signs at junctions		
☐ c. Attitude of other road users		
☐ d. Routes availability and Obstruction free routes.		
☐ e. Shower and other facilities at the destination		
☐ f. Journey time consideration		
☐ g. Capability for luggage carrier		

16. If your concerns in Q15are addressed, what is the likelihood of you adopting active transport for your short journey?

	Very Unlikely	*Somewhat Unlikely*	*Neither Likely Nor Unlikely*	*Somewhat Likely*	*Very Likely*
a. Sidewalk ways /Cycle paths/Footpaths etc.	○	○	○	○	○
b. Crossing and road signs at junctions	○	○	○	○	○
c. Attitude of other road users	○	○	○	○	○
d. Routes availability and Obstruction free routes.	○	○	○	○	○
e. Shower and other facilities at the destination	○	○	○	○	○
f. Journey time consideration	○	○	○	○	○
g. Capability for luggage carrier	○	○	○	○	○

Appendix A1:A3 Boxplots for Non-motorised travellers

The boxplots in Figure A 1 shows the distributions of the set of travellers stereotyped as group 1 (i.e., the right arm of the dendrogram from height 3) as shown in Figure 6.2.

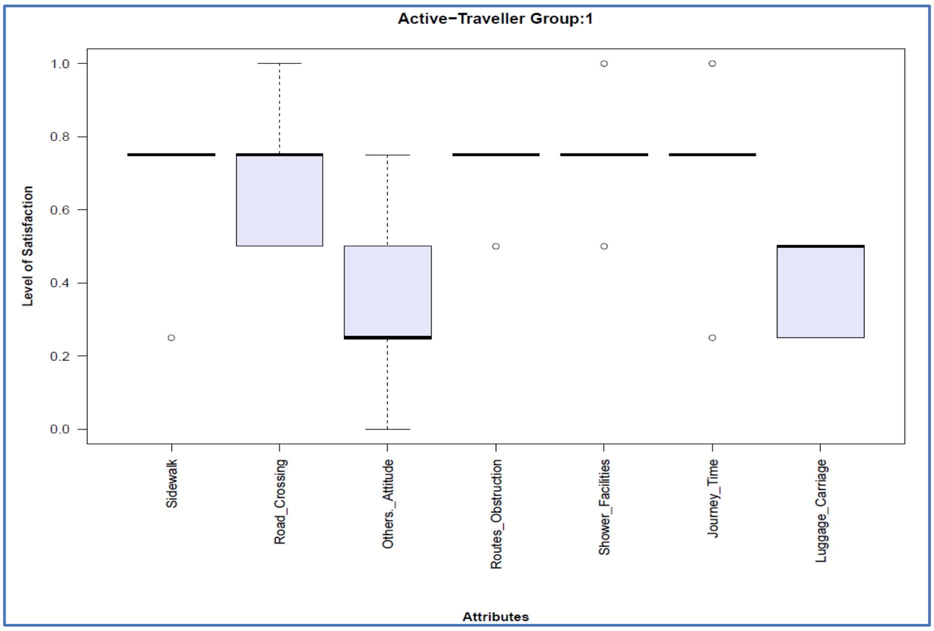


Figure A 1: Boxplot for Non-motorised travellers' group 1

The members of group 1 are satisfied in all the aspects of the non-motorised travel mode attributes with the median of 0.78 satisfaction level except in the *other travellers' attitude* and *luggage carrier* attributes where the group is most dissatisfied with a mean value of 0.25, third quarter-bound of 0.48 and lower bound 0.0. The distributions on the *luggage carrier* shows that half of the members' satisfaction level is below the mean value of 0.5, hence they are considered dissatisfied in this aspect. Few outliers around the upper, middle and lower bound of the *sidewalk* and *journey-time* attributes are indications of dissatisfaction with these attributes.

Figure A 2 is the boxplots representation of the travellers stereotyped as group 2 (the middle arm of the dendrogram from height 3) in Figure 6.2. The distributions in the boxplots indicate that this group is satisfied in all aspects of their non-motorised travel mode.

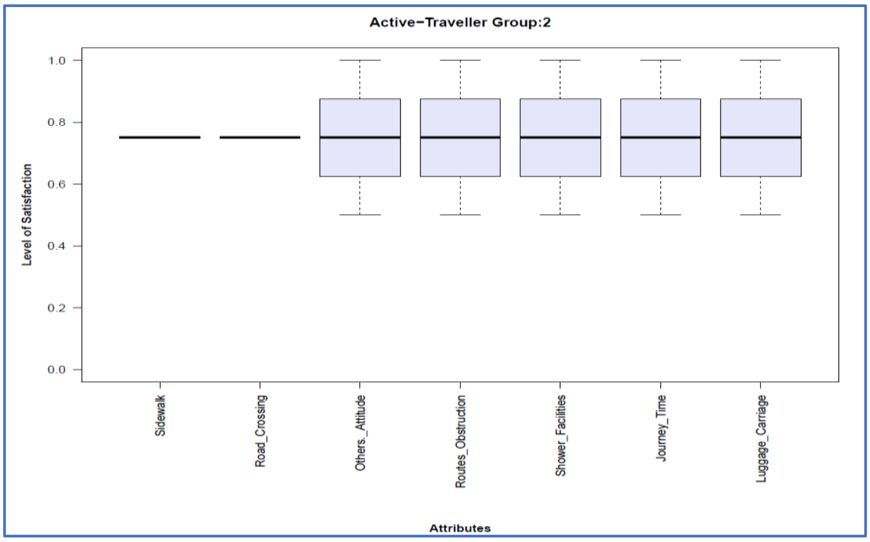


Figure A 2:Boxplot for Non-motorised travellers' group 2

This is evident in the boxplot's distributions with a median value of 0.78 and the lower quartile of 0.5. In general, the group represent the most satisfied travellers' category.

The boxplot distributions in Figure A 3 represents non-motorised traveller group 3 (the left arm of the dendrogram from height 3).

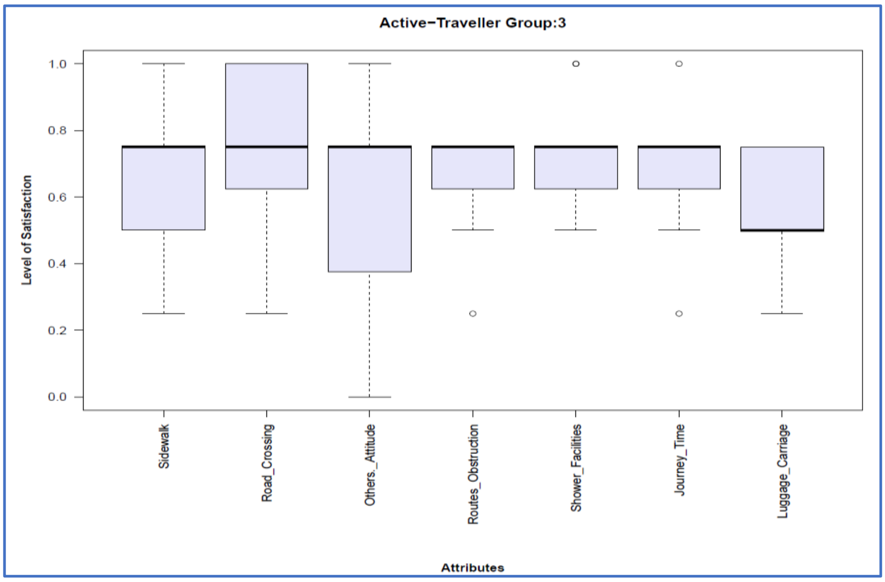


Figure A 3:Boxplot for Non-motorised travellers' group 3

Members of the group show dissatisfaction in more attributes of the travel mode than the other two groups. Although, the median value for all attributes' perceptions is at 0.78 except in the *luggage carrier* that has 0.5. The group members show more dissatisfaction with the *others travellers' attitude* attribute; 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.

Appendix B: 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 the 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: 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 ☐ Weekdays commuting to/from education

☐ Business travel

Q5: Which of the following best describes your occupation?

☐ Professor/Senior Academics ☐ Skilled Manual

☐ Other Academics ☐ Unskilled Manual

☐ Professional/Senior Managerial ☐ Full-time Student

☐ Middle Managerial/Administrative ☐ Part-time student

☐ Junior Managerial/Clerical ☐ 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 (Question3 takes care of your primary mode).

☐ Car ☐ Tram ☐ Bicycle

☐ Bus or Coach ☐ Motorcycle ☐ Walking

☐ Rail ☐ Taxi ☐ 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	○	○	○	○	○	○
	Very Unimportant	*Somewhat Unimportant*	*Neither Important Nor Unimportant*	*Somewhat Important*	*Very Important*	*Not Applicable*
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*	*SomewhatSatisfied*	*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?

Appendix C: Data Analysis for Cyclist Population

Table C 1: Classification Analysis Result for the Cyclist Population

Reliability Affective	Reliability Perception	Ease Of Information Affective	Ease Of Information Perception	Ease To Destination Affective	Ease To Destination Perception	Getting On Off Affective	Getting On Off Perception	Parking Concern Affective	Parking Concern Perception	Delays Affective	Delays Perception	Security Affective	Security Perception	Safety Affective	Safety Perception	Road Signs Affective	Road Signs Perception	Others Attitude Affective	Others Attitude Perception	Walking To Destination Affective	Walking To Destination Perception	Weather Protection Affective	Weather Protection Perception	Overall Satisfaction
0.528187	0.25	0.2546595	0.25	0.732104	0.75	0.803713	0.75	0.397448	0.25	0.475058	0.25	0.397448	0.25	0.254659	0.25	0.803713	0.75	0.591942	0.5	0.803713	0.75	0.10912	0	0.5
0.600663	0.5	0.5281872	0.5	0.732104	0.75	0.803713	0.75	0.600663	0.5	0.528187	0.5	0.600663	0.5	0.397448	0.25	0.803713	0.75	0.591942	0.5	0.803713	0.75	0.397448	0.25	0.75
0.600663	0.5	0.6006628	0.5	0.803713	0.75	0.871733	1	0.600663	0.5	0.528187	0.5	0.776582	0.75	0.600663	0.5	0.803713	0.75	0.600663	0.5	0.803713	0.75	0.600663	0.5	0.875
0.803713	0.75	0.8037134	0.75	0.891775	1	0.891775	1	0.803713	0.75	0.600663	0.75	0.803713	0.75	0.600663	0.5	0.803713	0.75	0.600663	0.5	0.803713	0.75	0.600663	0.5	1
0.803713	0.75	0.891775	1	0.892705	1	0.891775	1	0.891775	1	0.600663	1	0.891775	1	0.803713	0.75	0.803713	0.75	0.600663	0.5	0.803713	0.75	0.891775	0.75	1
0.572713	1.25	0.4785698	1.25	0.732104	0.75	0.732104	1	0.347664	0	0.324973	0.25	0.284811	0.25	0.10912	0	0.324973	0.25	0.10912	0	0.478542	0.75	0.10912	0	0.5
0.572713	1.25	0.5281872	1.25	0.732104	0.75	0.79947	1	0.600663	0.5	0.528187	0.5	0.528187	0.5	0.368078	0.25	0.572713	0.5	0.387397	0.25	0.600663	1	0.368078	0.25	0.75
0.600663	1.25	0.5281872	1.25	0.797505	0.75	0.836438	1	0.600663	0.5	0.596287	0.5	0.600663	0.75	0.397448	0.25	0.600663	0.5	0.528187	0.5	0.776582	1	0.397448	0.25	0.75
0.600663	1.25	0.6006628	1.25	0.803713	0.75	0.891775	1	0.82505	1	0.732104	0.75	0.776582	0.75	0.600663	0.5	0.803713	0.75	0.600663	0.75	0.836438	1.25	0.600663	0.5	1
0.600663	1.25	0.6006628	1.25	0.892705	0.75	0.891775	1	0.891775	1	0.892705	1	0.803713	1	0.803713	0.75	0.836438	1	0.82505	1.25	0.891775	1.25	0.803713	0.75	1
0.572713	0.75	0.5281872	1.25	0.803713	1	0.871733	1	0.797505	0.5	0.47857	0.5	0.776582	0.75	0.397448	0.25	0.776582	0.5	0.572713	0.5	0.572713	0.75	0.47857	0.5	1
0.600663	1	0.5281872	1.25	0.836438	1	0.871733	1	0.803713	0.75	0.528187	0.75	0.776582	0.75	0.600663	0.5	0.776582	0.75	0.600663	0.75	0.600663	0.75	0.572713	0.5	1
0.600663	1.25	0.5281872	1.25	0.836438	1	0.891775	1	0.871733	1	0.732104	1	0.803713	0.75	0.803713	0.75	0.803713	0.75	0.600663	1	0.803713	1	0.600663	0.75	1
0.803713	1.25	0.5281872	1.25	0.891775	1	0.891775	1	0.891775	1	0.836438	1.25	0.803713	0.75	0.803713	0.75	0.803713	1	0.803713	1.25	0.871733	1.25	0.803713	0.75	1
0.891775	1.25	0.5281872	1.25	0.892705	1	0.891775	1	0.891775	1.25	0.836438	1.25	0.803713	0.75	0.891775	1	0.803713	1.25	0.891775	1.25	0.891775	1.25	0.803713	0.75	1
0.528187	0.75	0.4785422	0.75	0.528187	0.5	0.478542	0.75	0.284811	0.5	0.478542	0.75	0.732104	0.75	0.732104	0.75	0.776582	0.5	0.528187	0.5	0.368078	0.25	0.324973	0	0.5
0.572713	1	0.5281872	1	0.732104	0.75	0.600663	1	0.572713	0.75	0.542573	1	0.776582	0.75	0.776582	0.75	0.776582	0.75	0.591942	0.75	0.528187	0.75	0.572713	0.5	0.75
0.600663	1.125	0.5727134	1	0.836438	1	0.790148	1	0.754343	1	0.594114	1.25	0.79947	1	0.803713	0.75	0.803713	0.75	0.766868	1	0.600663	1	0.736289	0.75	1
0.871733	1.25	0.8364376	1.25	0.890278	1	0.871733	1.25	0.836438	1	0.803713	1.25	0.871733	1	0.871733	1	0.836438	1	0.836438	1.25	0.803713	1.25	0.803713	1	1
0.891775	1.25	0.891775	1.25	0.892705	1.25	0.891775	1.25	0.891775	1.25	0.890278	1.25	0.891775	1.25	0.891775	1	0.891775	1	0.891775	1.25	0.891775	1.25	0.891775	1.25	1.25

C2: The Cyclists' Contextual Activity Template with Physical, Cognitive and Affective Indications

The cyclists' contextual activity template with physical, cognitive, and affective (CAT-PCA) considerations is shown in Figure C 1. Considering the three general functions identified at the *purpose-related functions* of the AH discussed in Section 7.5.2 (i.e., *information provision, cater for tasks and biological needs, and protections*). In the *information provision* related functions that include general *mode information,* as well as the *traffic and route information,* there are representations for cognitive demand in almost all situations where the functions can occur. This can be attributed to the need to access, understand and plan around the available information.

Situations / Functions	Origin/ Destination	En-route to Mode Stop	At the Mode Stop	En-route to the university	At the University Storage facilities	En-route to destination
General mode information						
Traffic and route information						
Journey Planning						
Wayfinding						
Shelter from elements						
Mode Storage						
Personal safety						
Shelter from Unsavoury persons						

Figure C 1: Cyclist Contextual Activity Template with PCA indications

The *cater for biological need* (i.e. Shelter from elements) and *protections* functions which include *personal safety* and *shelter from unsavoury persons* have indications of cognitive and affective considerations. There are little or no physical efforts required to achieve the functions related to biological needs. In other words, the functions *shelter from elements*, and *mode storage* demand less physical, but cognitive efforts and large affective influence. Furthermore, some of the functions including *journey planning* and *wayfinding (i.e. cater for tasks need*) have indications of physical, cognitive and affective considerations. This makes sense for cyclists who need to plan to take the route that will demand less physical efforts as well as safe.

C3: Cyclist Population's Group Classification

The datasets for the clustering analysis on the cyclists' population is shown in Appendix C Table C1. The four groups resulting from the analysis are presented in the boxplots shown in Figures C2 to C5. The boxplots show the travellers' perceived satisfaction (i.e., cognitive and/or physical) and affective on the travel mode's attributes as well as overall satisfaction. Considering the four groups represented in the boxplots, groups 1 (Figure C2) and group 2 (Figure C3) are compared because of their varying levels of dissatisfaction. Group 3 (Figure C4) has properties that represent a fairly satisfied group, while group 4 (Figure C5) represents fully satisfied members of the population.

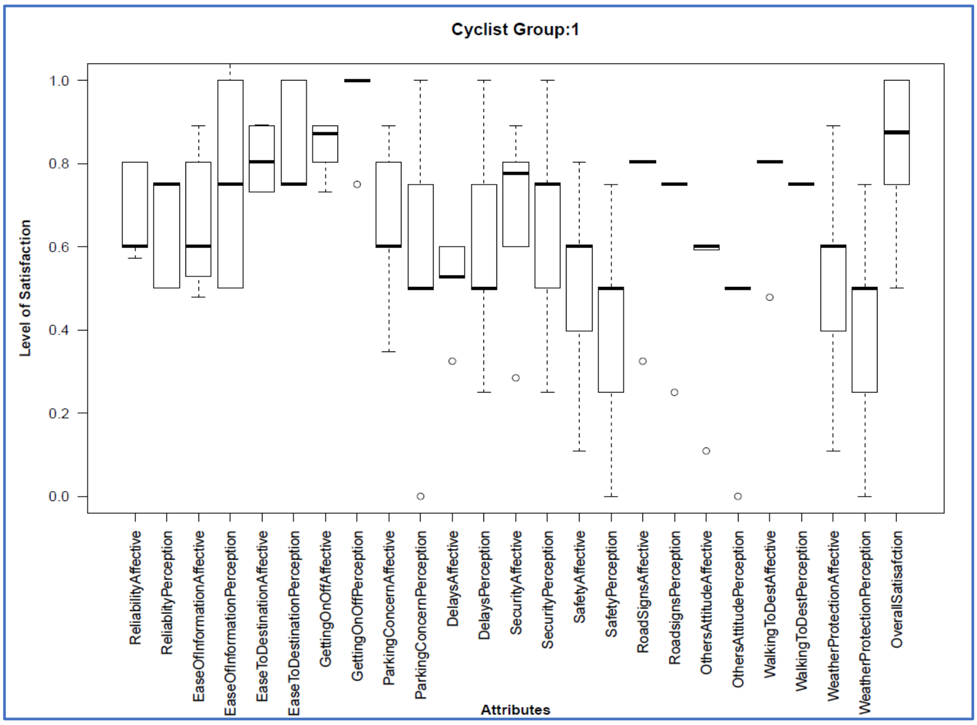


Figure C 2: Boxplot for Cyclists group 1

The common observable features in group 1 and group 2 are that they both showed dissatisfaction in the aspects of *weather protection* and *safety* of cycling. However, group 1 is most dissatisfied in these aspects as half of the group's population have a mean value below 0.5 level of satisfaction. In addition, group 1 also show dissatisfaction in the *delays* and *security* aspects where some members are below the lower quartile. Group 2 indicates dissatisfaction in *weather protection* and *safety* aspects as the mean values for both safety and weather protections are 0.4 and 0.2 levels of satisfaction, respectively.

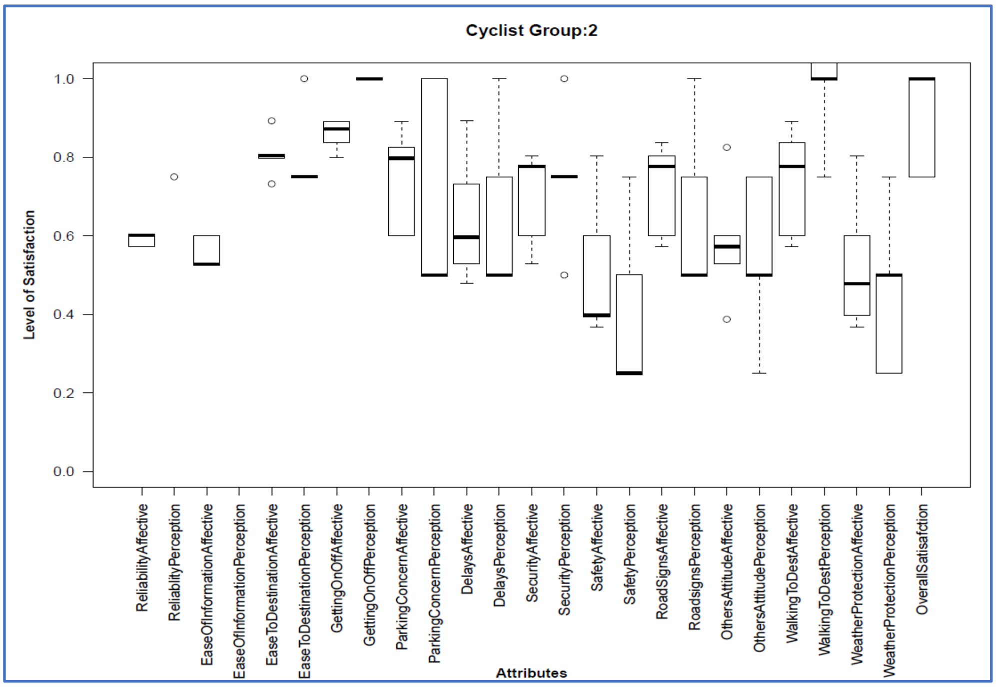


Figure C 3:Boxplot for Cyclist group 2

The boxplots for group 3 and group 4 have the mean values above the 0.5 level of satisfaction in all aspects of mode attributes.

Group 3 has few members that are dissatisfied in the aspect of *walking to the destination* from the mode storage.

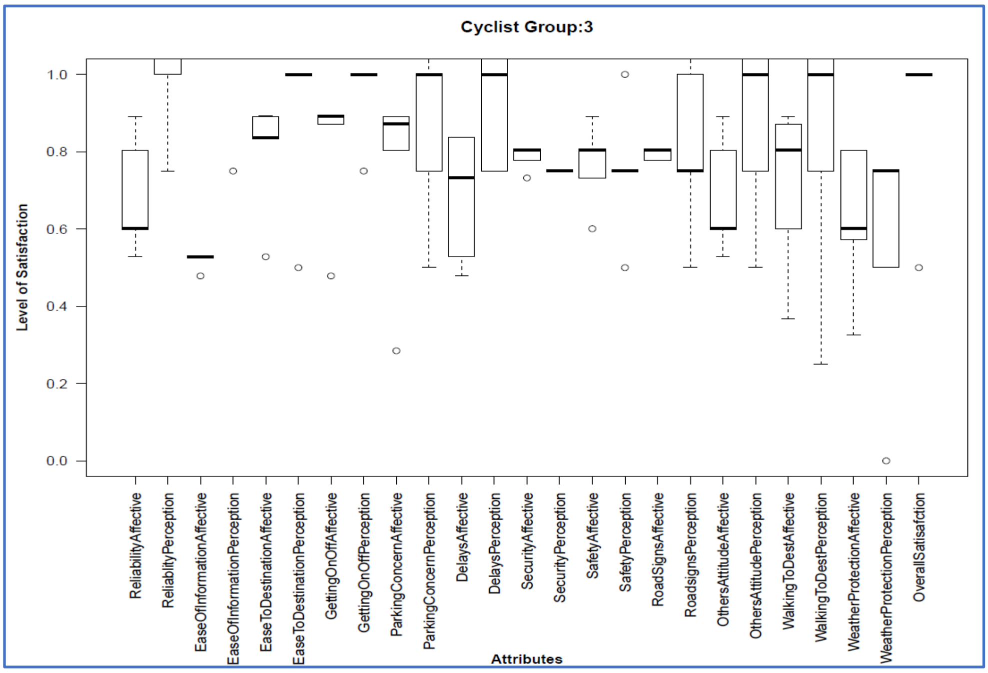


Figure C 4:Boxplot for Cyclist group 3

While members of group 4 are most satisfied among the four groups in all aspect of travel modes attributes, with the lower whisker of the boxplot above 0.5 level of satisfaction.

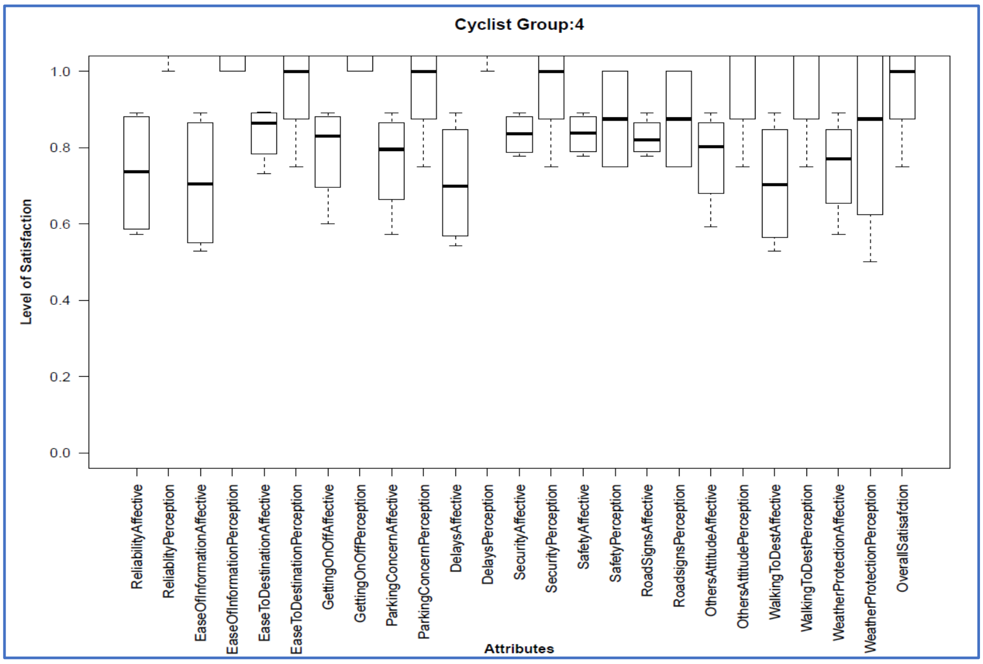


Figure C 5:Boxplot for Cyclists group 4

C4: The Textual Analysis of Cyclists' Concerns

Table C2 summarises the areas of concerns to the cyclists. From the table, all suggested solutions made by the cyclists centred around five values and priority measures of *safety, journey time, comfort, convenience and personal mobility*. This is due to the concerns for bad weather, the attitude of other road users, cycle lane obstructions and lack of route maintenance, inadequate cycle sheds and traffic delays etc. The strategies to stimulate cyclists' behaviours are formulated using the information provided in the table.

Table C 2: The Textual Analysis of Cyclists' Concerns and Responses

The aspects being investigated	Identified problems / Problem sub-category	Suggested Solution space	Related Defined Theme (criteria to measure performance)
Ease of accessing information.	-	-Offline access to information as in offline google maps.	-Journey-time. -Reliability.
Reliability of available information.	-	- Road closure and diversion information be more accurate and available on time.	-Reliability.
Ease of getting to destination on time.	-Indiscriminate parking of vehicles on cycle routes. -Traffic light delays.	-Priority for cyclists at junctions -Public awareness -Fines for obstructions	-Personal mobility. -Journey-time. -Safety.
Parking space concern.	-Insufficient cycle's parking sheds. -Difficult to find protected sheds.	-More protected cycle sheds across the university	-Convenience. -Security.
Delays.	-Indiscriminate parking of vehicles on cycle routes. -Traffic light delays. -No priority for cyclist at junctions. - Set out earlier than expected.	-The need for better cycle routes. -Campaigns and public awareness. -Fines for obstructions. -Provision of alternative routes during construction works. -Release information well before road diversion for construction works.	-Journey-time. -Personal mobility.
Security.	-Cycle theft due to inadequately protected sheds.	-More CCTV camera over cycle sheds.	-Safety/Security.
Safety on the main mode.	-Bad driving attitude threatens cyclists' safety - Muddy cycle tracks, and frozen road edges during winter -Indiscriminate parking of vehicles on cycle routes	-Campaign and awareness that cyclists are equal road users -Ensuring well-managed cycle lanes -Fines for bad driving attitude -Clearly marked and dedicated cycle lanes	-Safety/Security
Availability of Road signs.	-No good signage for cycle lanes. -No priority for cyclist at junctions.	-Good planning for cycle route signs.	-Safety. -Journey-time
Attitude of other road users.	-Rude and endangering behaviour by motorists.	-Awareness that cyclists are equal road users. -Sensitisation on the right of all road users.	-Safety.
Walking from the main mode to destination.	-	-	-
Protection from bad weather.	-No adequate cover during bad weather.	-Bigger shelter along cycle lanes apart from bus stops -Priority for cyclists at the junctions -Freecycling kits -Traffic lights should be configured to give way to cyclist during bad weather	-Comfort.

Appendix D: Data Analysis for Public transport users' Population

Table D 1: Classification Analysis Results for Public User Population

Reliability Affective	Reliability Perception	Ease Of Information Affective	Ease Of Information Perception	Ease To Mode Stop Affective	Ease To mode Stop Perception	Ease To Destination Affective	Ease To Destination Perception	Getting On/Off Affective	Getting On/Off Perception	Distance To Mode stop Affective	Distance To mode stop Perception	Frequency Of Mode Affective	Frequency Of Mode Perception	Delays Affective	Delays Perception	Security Affective	Security Perception	Safety Affective	Safety Perception	Road Signs Affective	Road Signs Perception	Others Attitude Affective	Others Attitude Perception	Walking To Destination Affective	Walking To Destination Perception	Weather Protection Affective	Weather Protection Perception	Overall Satisfaction
0.672863	0.5	0.672863	0.5	0.672863	0.5	0.672863	0.5	0.600663	0.5	0.528187	0.5	0.672863	0.5	0.393597	0	0.695996	1	0.672863	1	0.572713	1	0.600663	0.5	0.600663	0.5	0.672863	0.75	0.5
0.803713	0.75	0.803713	0.75	0.732104	0.75	0.793839	0.75	0.732104	0.75	0.695996	0.75	0.776582	0.75	0.596287	0.5	0.78436	1	0.803713	1	0.732104	1	0.757155	0.75	0.732104	0.75	0.776582	0.75	0.75
0.871733	1	0.871733	1	0.79947	1	0.803713	0.75	0.79947	1	0.78436	1	0.803713	0.75	0.79217	0.75	0.871733	1	0.891775	1	0.871733	1	0.803713	1	0.78436	1	0.803713	1	1
0.891775	1	0.891775	1	0.836438	1	0.890278	1	0.836438	1	0.836438	1	0.891775	1	0.803713	1	0.891775	1	0.891775	1	0.891775	1	0.890278	1	0.836438	1	0.891775	1	1
0.891775	1.25	0.891775	1	0.891775	1.25	0.892705	1	0.891775	1.25	0.891775	1.25	0.891775	1	0.892705	1.25	0.891775	1	0.891775	1	0.891775	1	0.891775	1.25	0.891775	1.25	0.891775	1.25	1
0.368078	0.25	0.254659	0.25	0.254659	0.25	0.221311	0	0.254659	0.25	0.254659	0.25	0.324973	0.25	0.173191	0	0.21463	0.25	0.254659	0.25	0.397448	0.25	0.237867	0.25	0.254659	0.25	0.324973	0.25	0.25
0.572713	0.5	0.528187	0.5	0.528187	0.5	0.378778	0.25	0.47857	0.5	0.478542	0.5	0.397448	0.25	0.368078	0.25	0.528187	0.5	0.528187	0.5	0.572713	0.5	0.551851	0.5	0.47857	0.5	0.572713	0.5	0.5
0.688622	0.625	0.732104	0.75	0.695996	0.75	0.525628	0.5	0.695996	0.75	0.695996	0.75	0.600663	0.5	0.397448	0.25	0.586688	0.5	0.776582	0.75	0.600663	0.75	0.600663	0.5	0.528187	0.5	0.776582	0.75	0.75
0.803713	0.75	0.803713	0.75	0.732104	0.75	0.764368	0.75	0.732104	0.75	0.732104	0.75	0.776582	0.75	0.591942	0.5	0.776582	0.75	0.803713	0.75	0.776582	1	0.776582	0.75	0.695996	0.75	0.776582	0.75	0.75
0.891775	1	0.891775	1	0.836438	1	0.803713	0.75	0.871733	1	0.836438	1	0.891775	1	0.803713	0.75	0.871733	1	0.891775	1	0.891775	1.25	0.803713	0.75	0.732104	0.75	0.891775	1	1
0.776582	0.5	0.776582	0.75	0.695996	0.5	0.764368	0.5	0.47857	0.5	0.572713	0.5	0.732104	0.5	0.387397	0.25	0.528187	0.5	0.324973	0.25	0.284811	0.25	0.757155	0.5	0.478542	0.5	0.284811	0.25	0.5
0.803713	0.75	0.803713	0.75	0.776582	0.75	0.79217	0.75	0.672863	0.75	0.695996	0.75	0.776582	0.75	0.591942	0.5	0.572713	0.5	0.572713	0.5	0.572713	0.5	0.776582	0.75	0.528187	0.5	0.528187	0.5	0.75
0.803713	0.75	0.871733	1	0.836438	1	0.799541	0.75	0.79947	1	0.78436	1	0.803713	0.75	0.688622	0.625	0.600663	0.5	0.776582	0.75	0.600663	0.625	0.803713	0.75	0.732104	0.75	0.776582	0.75	0.75
0.891775	1	0.891775	1	0.836438	1	0.890278	1	0.836438	1	0.836438	1	0.871733	1	0.803713	0.75	0.803713	0.75	0.803713	0.75	0.803713	0.75	0.871733	1	0.776582	0.75	0.871733	1	1
0.891775	1	0.891775	1	0.891775	1	0.892705	1.25	0.871733	1.25	0.871733	1.25	0.891775	1.25	0.892705	1	0.891775	1	0.891775	1	0.891775	1	0.891775	1	0.871733	1	0.891775	1	1

D3: Public transport Users' Population Group Classification

The datasets for the clustering analysis result from the public transport users' population is shown in Table D1 (Appendix D). The boxplot representations of the datasets are shown in Figure D1, Figure D2 and Figure D 3.

Considering the three boxplots that represent the public transport users' population groups, the mean values of the distribution in all aspect considered is above 0.5 level of satisfaction except in group 2 *delays* and *frequency* attributes perception.

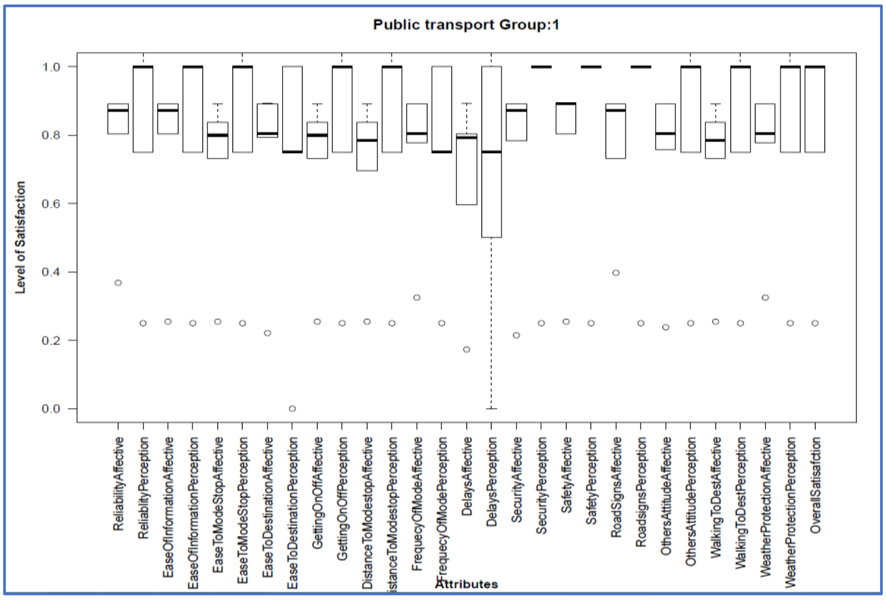


Figure D1: Boxplot for Public transport user group1

The members of the group classified as group 1 are satisfied in all aspects of public transport attributes considered except the less than 25% of the population that showed dissatisfaction in their experiences regarding delays in journeys.

Group 2 is the most dissatisfied among the three stereotypes. 75% of the population showed concerns about the *delays* due to the bus frequency of the travel mode.

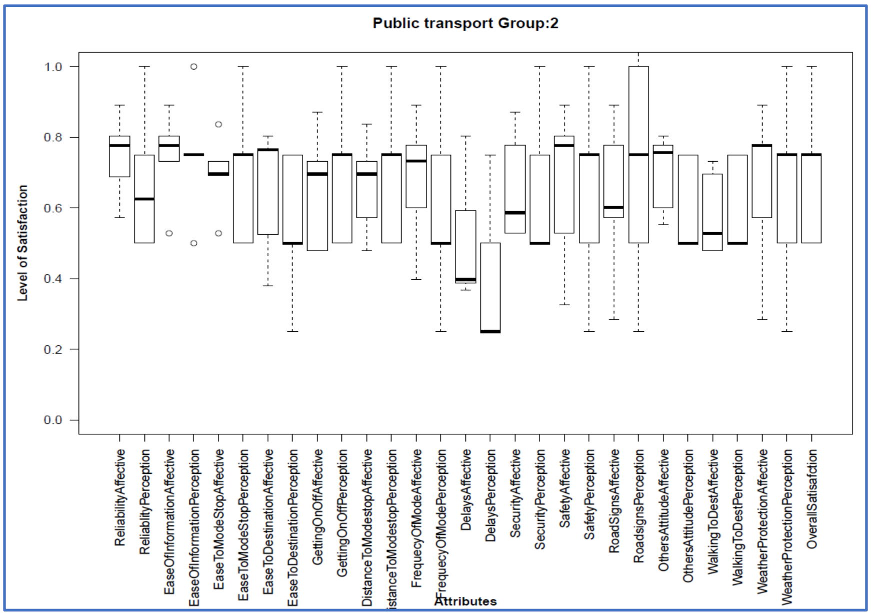


Figure D2: Boxplot for Public transport user group 2

Also, in group 2, less than 25% of the travellers in the group are dissatisfied with the *ease of getting to the destination, frequency of the mode, safety*, and *protection from elements* at the bus stops.

Lastly, group 3 (i.e., Figure D 4) represents the most satisfied group.

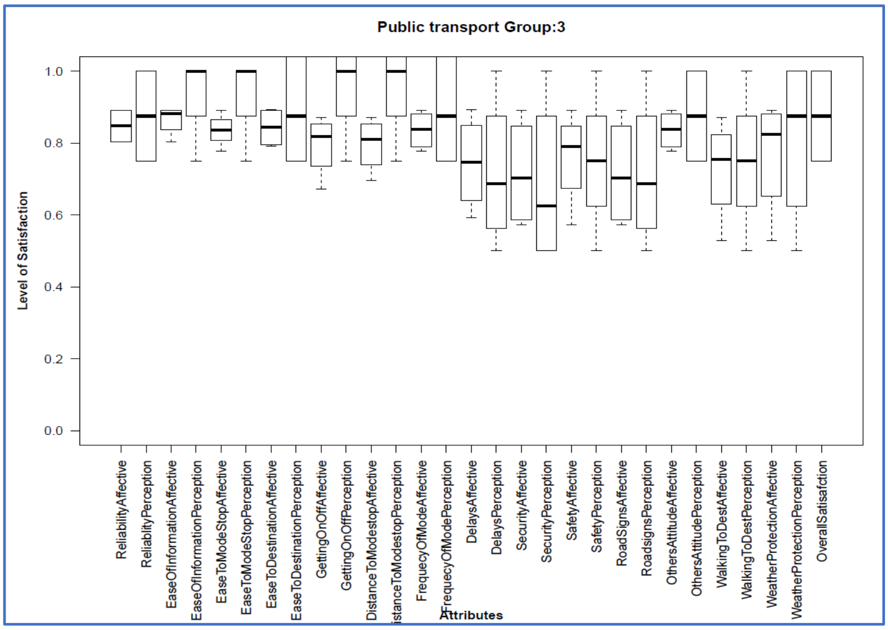


Figure D 3: Boxplot for Public transport user group 3

All members of the group are represented within the minimum value (lower whisker) of the boxplot above 0.5 level of satisfaction.

D4: The Textual Analysis of Public transport users' Concerns

Table D 2 summarises the concerns and suggestions for possible solutions to public transport users to the university. The concerns include delays due to the *reliability* and the bus journey-*time*; *convenience* regarding ease of getting to the bus stop as well as walking to the destination; *comfort* in the aspects of sitting provisions and protection from elements at the bus stop. The suggested possible solutions are categorised to be related to four values and priority measures of *reliability, journey time, comfort and convenience*.

Table D 2: The textual analysis of Public transport user's response

The aspects being investigated	Identified problems / Problem sub-category	Suggested Solution space	Related Defined Theme (criteria to measure performance)
Ease of accessing information.	-Difficulties in accessing information outside the origin/destination.	- Off-line information access could be helpful.	-Reliability.
Reliability of available information.	-Most of the times the bus failed to arrive as advertised.	-Improvements in keeping to advertised information.	Reliability.
Ease of getting to destination on time.	-	-	-
Ease of getting to main travel mode.	Set out earlier than excepted due to the distance to the bus stops.	-Local link buses should be introduced on the routes where there are none.	-Convenience.
Getting On and Off the mode.	-	-	-Convenience.
Frequency of the main mode.	-Sometimes the frequency of the buses is not as advertised hence, causing lateness. - No enough buses.	-Buses to the university are made more frequent than its current operations. -Introduction of additional buses.	-Journey-time.
Distance to the main mode.	Set out earlier than excepted due to the distance to the bus stops.	-Local link buses should be introduced on the routes where there are none.	Convenience.
Delays.	Lack of reliability, timeliness and frequency of the buses caused delays.	-More buses should be introduced into the route and operates as advertised.	-Reliability. -Journey-time.
Safety/Security en-route the mode.	-Some passengers behaviours could be scary sometimes.	-	-Safety.
Attitude of other road users.	-Some passengers behave unpleasantly sometimes.		-Safety. -Convenience.
Walking from the main mode (bus stop) to destination.	-	-	-
Protection from bad weather.	-No adequate cover during bad weather while moving to and from the bus stop.	- Bus stops should be provided where there is currently none and bigger ones be added.	-Comfort.

Appendix E: Data Analysis for Pedestrian Population

Table E 1: Classification Analysis Result for Pedestrian Population

Reliability Affective	Reliability Perception	Ease Of Information Affective	Ease Of Information Perception	Ease To Destination Affective	Ease To Destination Perception	Security Affective	Security Perception	Safety Affective	Safety Perception	Road Signs Affective	Road Signs Perception	Others Attitude Affective	Others Attitude Perception	Weather Protection Affective	Weather Protection Perception	Overall Satisfaction
0.397448	0.25	0.397448	0.5	0.732104	0.5	0.732104	1	0.776582	1	0.732104	0.5	0.397448	0.25	0.528187	0.5	0.5
0.600663	0.75	0.672863	0.75	0.797505	0.75	0.776582	1	0.803713	1	0.776582	0.75	0.600663	0.75	0.695996	0.75	0.75
0.776582	1	0.803713	1	0.836438	1	0.836438	1	0.881754	1	0.836438	1	0.776582	1	0.780471	0.75	0.75
0.891775	1.25	0.871733	1	0.884364	1	0.891775	1	0.891775	1	0.891775	1	0.858415	1.25	0.871733	1	1
0.891775	1.25	0.891775	1.25	0.892705	1	0.891775	1	0.891775	1	0.891775	1.25	0.891775	1.25	0.891775	1.25	1.25
0.478542	0.75	0.478542	0.5	0.591942	0.5	0.478542	0.5	0.478542	0.5	0.478542	0.5	0.471735	0.75	0.131054	0	0.5
0.528187	1	0.528187	0.75	0.732104	0.75	0.572713	0.75	0.600663	0.75	0.672863	0.75	0.572713	1	0.324973	0.25	0.75
0.600663	1.25	0.600663	1.25	0.836438	1	0.776582	0.75	0.791915	0.75	0.776582	0.75	0.600663	1.25	0.368078	0.25	1
0.836438	1.25	0.803713	1.25	0.884364	1	0.803713	1	0.871733	1	0.803713	1	0.79947	1.25	0.528187	0.5	1
0.891775	1.25	0.891775	1.25	0.892705	1.25	0.891775	1.25	0.891775	1.25	0.891775	1.25	0.891775	1.25	0.600663	0.5	1.25
0.397448	0	0.173191	0	0.102003	0	0.10912	0	0.284811	0.25	0.10912	0	0.284811	0	0.10912	0	0.25
0.528187	0.5	0.55045	0.5	0.429361	0.375	0.326444	0.25	0.438009	0.375	0.397448	0.25	0.47857	0.75	0.368078	0.25	0.5
0.572713	0.75	0.600663	0.75	0.666383	0.75	0.528187	0.5	0.572713	0.5	0.586688	0.5	0.562282	1.25	0.55045	0.75	0.75
0.754343	1	0.820075	1	0.847426	1	0.600663	0.5	0.600663	0.5	0.776582	0.75	0.666383	1.25	0.754343	1	0.75
0.891775	1.25	0.891775	1.25	0.892705	1.25	0.732104	0.75	0.776582	0.5	0.891775	1	0.891775	1.25	0.891775	1.25	1

E2: The Pedestrian Contextual Activity Template with Physical, Cognitive and Affective Indications

Figure E 1 is the contextual activity template with PCA (CAT-PCA) for the pedestrian group. The figure shows that all functions require pedestrians' cognitive and affective considerations in all situations that they can occur.

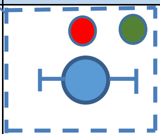
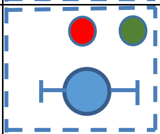
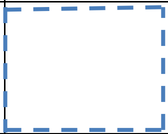
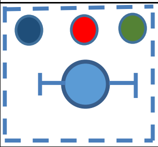
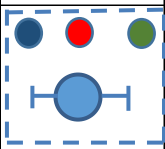
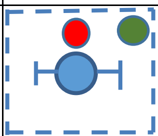
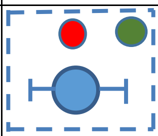
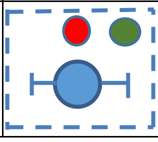
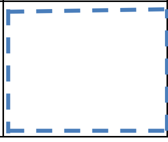
Situations / Functions	Origin/ Destination	En-route to Mode Stop	At the Mode Stop	En-route to the university	At the University Storage	En-route to destination
General mode information						
Travel mode routes Networks						
Journey Planning						
Wayfinding						
Shelter from elements						
Personal safety						
Shelter from Unsavoury persons						

Figure E 1: Pedestrian Contextual Activity Template with PCA indications

In addition, *journey planning* and *wayfinding* require pedestrians' physical effort to move around in order to locate a suitable route. However, in the case of car users, the same *wayfinding* function does not require physical consideration due to the motorised nature of the mode.

E3: Pedestrian Population Group Classification

The datasets representation of the classification analysis result for the pedestrians' population is shown in Table E1 (Appendix E). The three groups resulting from the analysis is presented in Figure E 2, Figure E 3, and Figure E 4 as group1 group2 and group3 respectively.

Group 1 represents the pedestrians' population that is satisfied in all aspects of walking with the mean value of all variables considered are above 0.78.

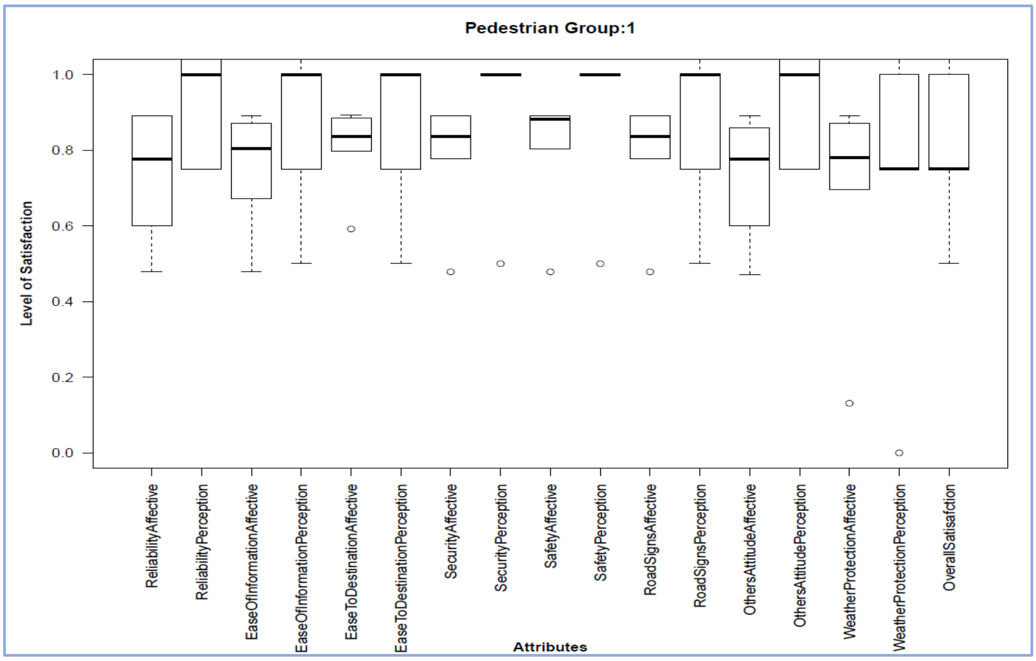


Figure E 2: Boxplot for Pedestrian group 1

Groups 2 represent members that are satisfied with the mean value of variable above 0.5 except in the aspect of *weather protection* which has a mean of 0.25.

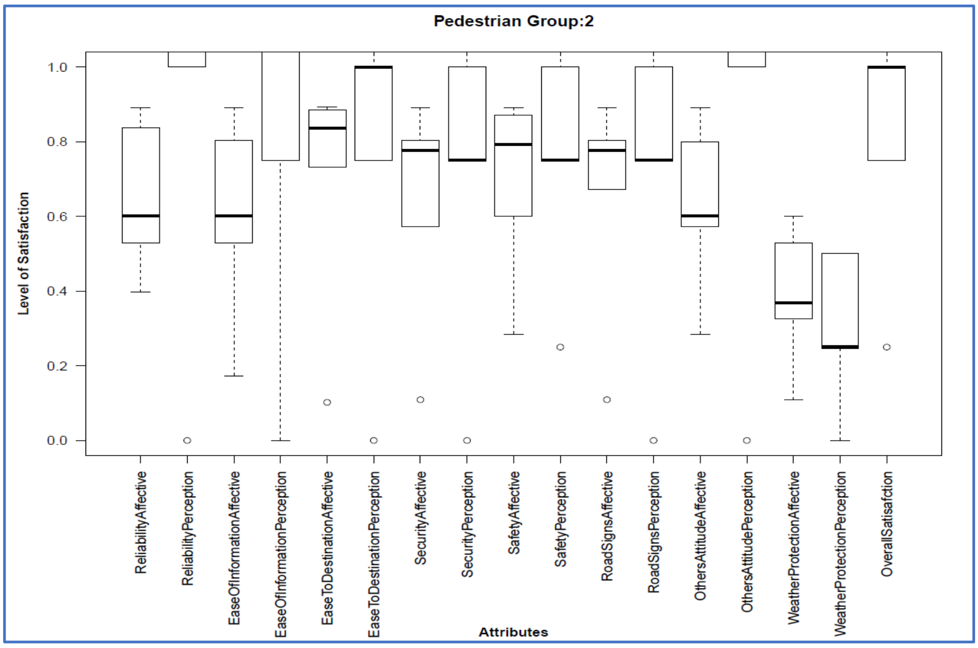


Figure E 3: Boxplot for Pedestrian group 2

Group 2 is dissatisfied in aspects such as *other travellers' attitude, safety,* and *ease of accessing information* where the lower whisker is at 0.25 and below.

The proportion of the population that belongs to group 3 are relatively satisfied with few members of the group having concerns in *weather protection, road sign availability* and *security* aspects.

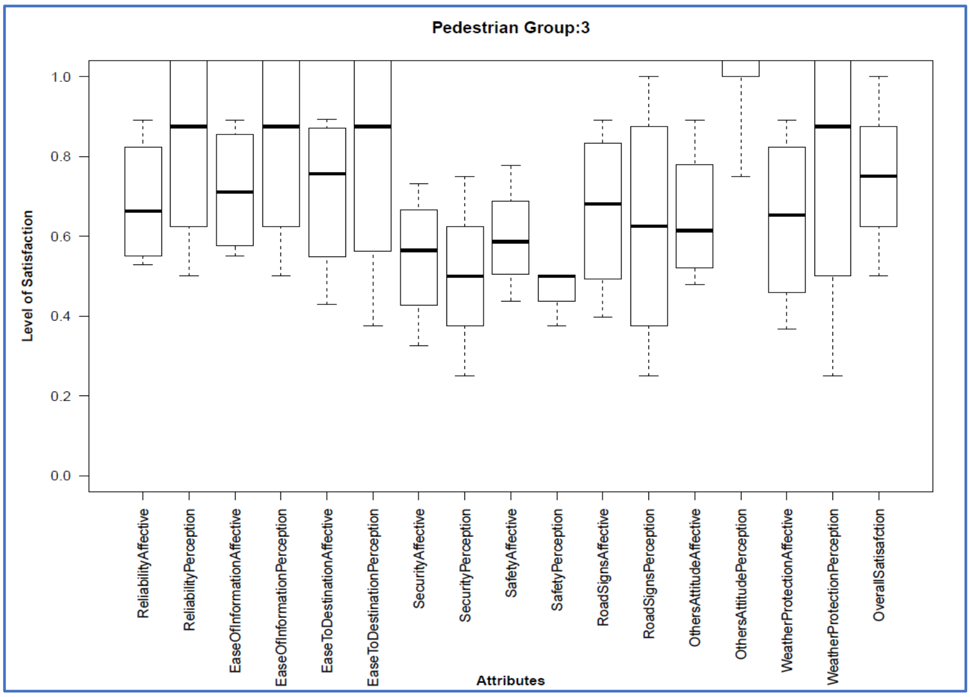


Figure E 4: Boxplot for Pedestrian group 3

E4: The Textual Analysis of Pedestrians' Concerns

The concerns expressed by the pedestrians and the possible suggestions to alleviate their dissatisfied experiences regarding these concerns are summarised in Table E 2. The pedestrians perceived as unsatisfied their *comfort* experience regarding bad weather; hindrances to *personal mobility* as a result of pavements cutting edges and crossing facilities too far apart; *safety* and *security* due to other road users' attitude as well as reliable weather information. The possible suggestions on how to resolve travellers' concerns are classified under the following aspects of values and priority measures: *reliability, journey time, comfort, safety, and personal mobility*.

Table E 2: The textual analysis of Pedestrians' response

The aspects being investigated	Identified problems / Problem sub-category	Suggested Solution space	Related Defined Theme (criteria to measure performance)
Ease of accessing information.	-Difficulties in accessing information outside the origin/destination.	- Off-line information access could be helpful.	-Reliability.
Reliability of available information.	- Sometimes weather information not accurate, therefore expose people to bad weather.	-	Reliability.
Ease of getting to destination on time.	-Pathways cutting edges widely open over pavements can be harmful and blocking paths.	- Regular routes and pathways maintenance.	-Personal mobility.
Delays.	- Road obstructions and diversions without prior notice do prolong journey time.	-Provide information about possible diversions well before it occurs.	-Journey-time.
Safety/Security en-route the mode.	-Pathways cutting edges could cause accidents	-Regular routes and pathways maintenance.	-Safety.
Availability of signs (pedestrian crossing).	-Crossing facilities are too far apart in some areas. -No considerations for pedestrians during bad weather at road crossings.	- Crossing facilities could be made closer. -The traffic light could be configured to give priority to pedestrians during bad weather.	-Safety. -Comfort.
Attitude of other road users.	-Motorist and cyclist pay little attention to pedestrians sometimes.	-Public awareness and campaigns on the right of all road users. -Legislation against the bad attitude.	-Safety.
Protection from bad weather.	-Unfavourable weather conditions.	- Apart from the usual bus stop, probably provision of shelters along the paths could help during bad weather	-Comfort.

Appendix F: Data Analysis for Car user Population

Table F 1: Classification Analysis Result for the Car User Population

Reliability Affective	Reliability Perception	Ease Of Information Affective	Ease Of Information Perception	Ease To Destination Affective	Ease To Destination Perception	Getting On/Off Affective	Getting On/Off Perception	Parking Concern Affective	Parking Concern Perception	Delays Affective	Delays Perception	Security Affective	Security Perception	Safety Affective	Safety Perception	Road Signs Affective	Road Signs Perception	Others Attitude Affective	Others Attitude Perception	Walking To Destination Affective	Walking To Destination Perception	Weather Protection Affective	Weather Protection Perception	Overall Satisfaction
0.528187	1	0.478542	1	0.732104	0.75	0.478542	0.75	0.347664	0.25	0.378778	0.25	0.672863	0.75	0.776582	0.5	0.732104	0.5	0.528187	0.5	0.478542	0.5	0.871733	1	1
0.600663	1	0.528187	1	0.799541	0.75	0.528187	1	0.560345	0.5	0.528187	0.5	0.732104	0.75	0.776582	0.75	0.776582	0.75	0.591942	0.75	0.572713	0.75	0.871733	1	1
0.600663	1.25	0.600663	1.25	0.836438	1	0.528187	1.25	0.764368	0.75	0.732104	0.75	0.776582	0.75	0.803713	0.75	0.803713	0.75	0.600663	1	0.776582	1	0.891775	1	1
0.891775	1.25	0.836438	1.25	0.884364	1	0.776582	1.25	0.803713	1	0.732104	0.75	0.803713	1	0.803713	1	0.891775	1	0.797505	1.25	0.836438	1.25	0.891775	1	1
0.891775	1.25	0.891775	1.25	0.892705	1	0.891775	1.25	0.892705	1.25	0.891775	1	0.891775	1.25	0.803713	1.25	0.891775	1	0.891775	1.25	0.891775	1.25	0.891775	1	1
0.368078	0.25	0.324973	0.25	0.799541	1	0.732104	0.75	0.572713	0.5	0.237867	0.25	0.776582	0.75	0.776582	0.75	0.776582	0.75	0.551851	0.5	0.732104	0.5	0.891775	1	1
0.572713	0.5	0.528187	0.5	0.836438	1	0.732104	0.875	0.664195	0.625	0.55045	0.5	0.776582	0.75	0.803713	0.75	0.803713	0.75	0.678909	0.625	0.776582	0.75	0.891775	1	1
0.600663	0.5	0.636763	0.625	0.891026	1	0.836438	1	0.776582	0.75	0.732104	0.75	0.776582	0.75	0.803713	0.75	0.803713	0.75	0.797505	0.75	0.836438	1	0.891775	1	1
0.803713	0.75	0.803713	0.75	0.891775	1	0.836438	1	0.794837	0.75	0.780937	0.75	0.803713	0.75	0.891775	1	0.891775	1	0.803713	0.75	0.836438	1	0.891775	1	1
0.891775	1	0.891775	1	0.892705	1	0.891775	1	0.884364	0.75	0.836438	1	0.803713	0.75	0.891775	1	0.891775	1	0.891775	0.75	0.871733	1	0.891775	1	1
0.397448	0	0.254659	0.25	0.368078	0.25	0.324973	1	0.173965	0	0.173191	0	0.478542	0.75	0.776582	0.5	0.528187	0.5	0.368078	0	0.324973	0.5	0.776582	0.75	0.75
0.600663	0.5	0.528187	0.5	0.592825	0.5	0.528187	1	0.362635	0.25	0.324973	0.25	0.648329	0.75	0.776582	0.75	0.688622	0.625	0.572713	0.5	0.528187	0.75	0.788026	0.875	0.75
0.688622	0.75	0.600663	0.75	0.732104	0.75	0.528187	1.25	0.519765	0.5	0.397448	0.25	0.776582	0.75	0.803713	0.75	0.803713	0.75	0.600663	0.75	0.732104	0.75	0.836438	1	1
0.803713	0.875	0.776582	0.75	0.800403	0.875	0.692511	1.25	0.572713	0.5	0.528187	0.5	0.803713	0.875	0.871733	1	0.803713	0.75	0.797505	1	0.754343	1	0.891775	1	1
0.891775	1.25	0.891775	1	0.892705	1	0.871733	1.25	0.8656	0.75	0.600663	0.5	0.891775	1	0.891775	1	0.891775	0.75	0.890278	1.25	0.871733	1.25	0.891775	1	1.25

F2: The Car-users' Contextual Activity Template with Physical, Cognitive and Affective Indications

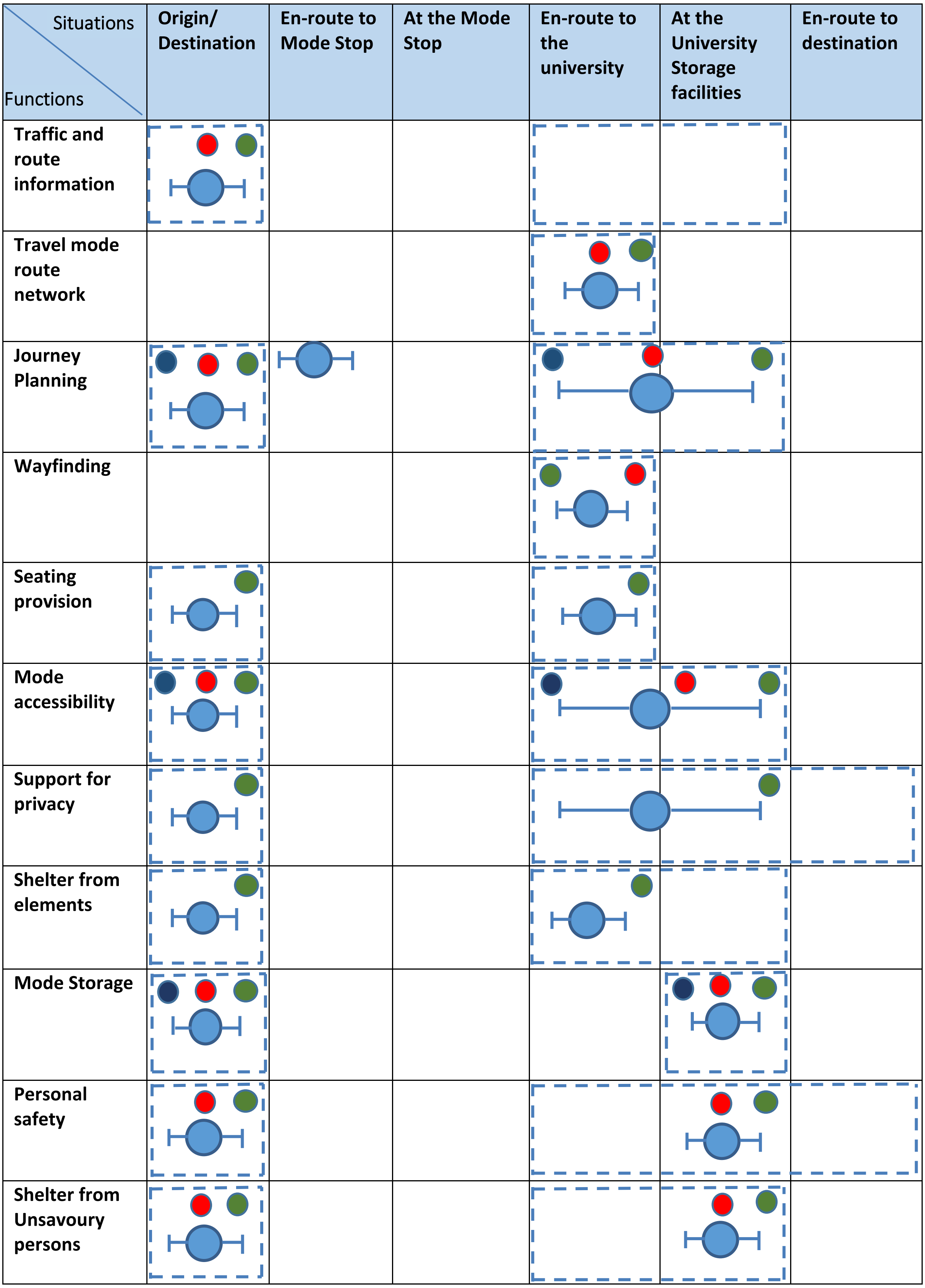


Figure F 1: Car user Contextual Activity Template with PCA Indications

In Figure F1 all functions that can be performed in the car use environment except *seating provisions, support for privacy* and *shelter from elements* require travellers' cognitive and affective considerations. The *seating provisions, support for privacy* and *shelter from elements* only have affective indications due to less cognitive and /or physical abilities involved in these functions. Also, *journey planning* and *mode storage* require all three requirements because planning involves locating suitable parking facilities that require less walk to the final destination. The *mode accessibility* function requires physical consideration to *get–on* and *get–off* the car, it therefore, has an indication of physical consideration in addition to the cognitive and affective aspects. Improvements are required in the provision of *traffic and route information, personal safety* and *shelter from unsavoury* persons at the en-route to the university and the final destination situations.

F3: Car user Population Group Classification

The datasets representation of the clustering analysis of the car users' population is presented in Table F1 (Appendix F). The boxplot representations of the datasets are shown in Figure F 2, Figure F 3, and Figure F 4 as groups 1, 2 and 3 respectively.

Groups 1 and 2 consists of the relatively satisfied population with the mean values of all attributes considered to be above 0.5 level of satisfaction.

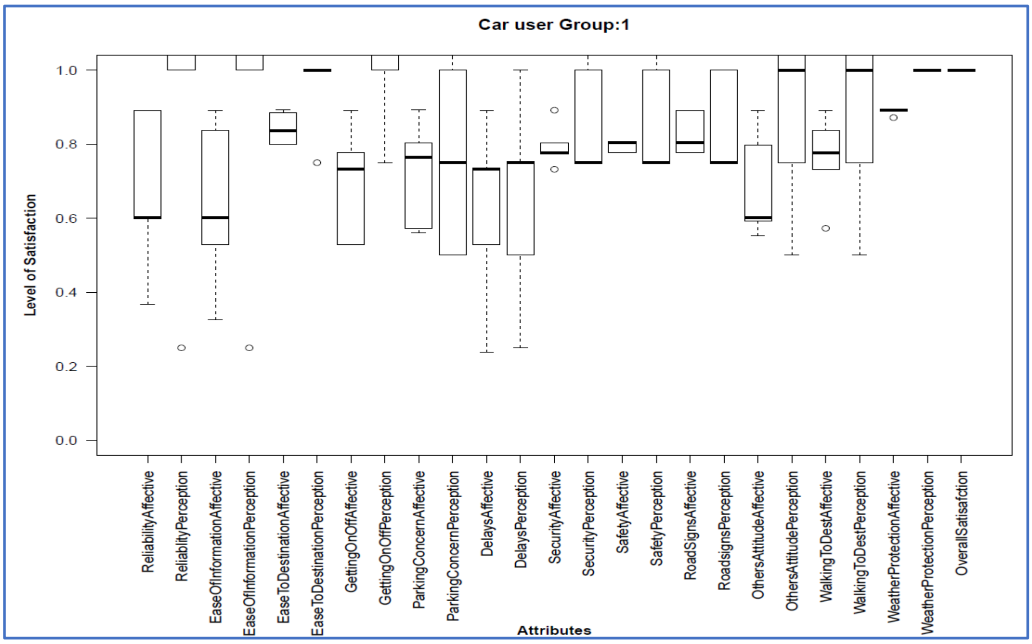


Figure F 2: Boxplot for Car user group 1

However, about 25% of the population of group 1 have concerns with *delays* due to traffic jam, and less than 25% of group 2 are concerned about the *ease of accessing information*.

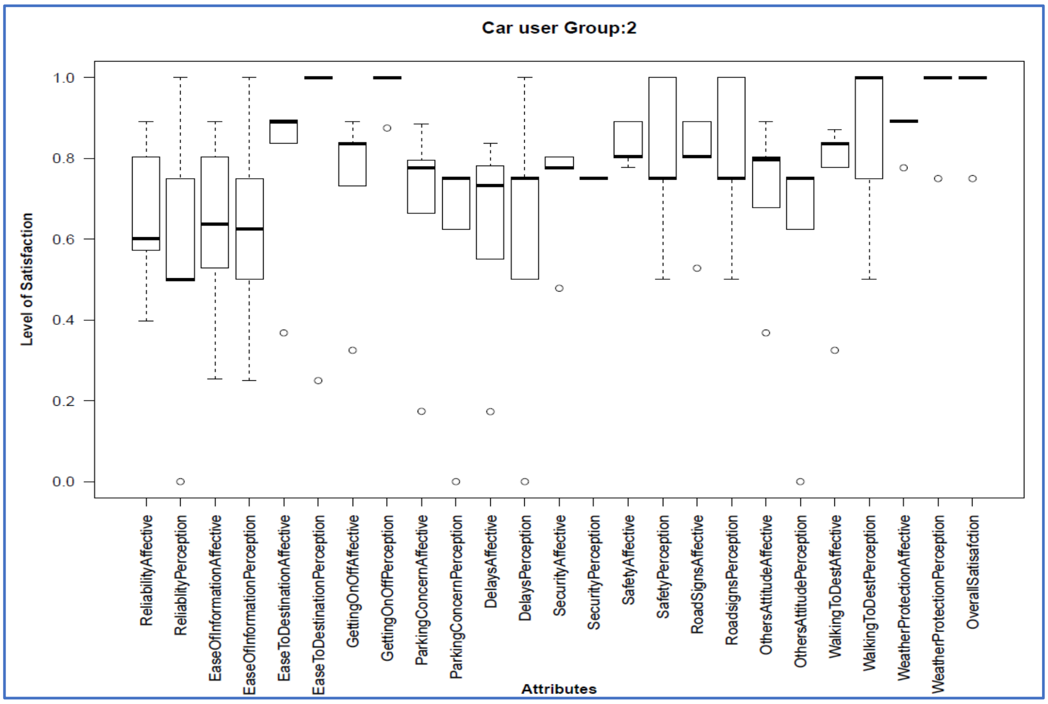


Figure F 3: Boxplot for Car user group 2

Group 3 are most concerned about the *delays* and *parking*-related issues including parking distance from final destinations and high parking fee.

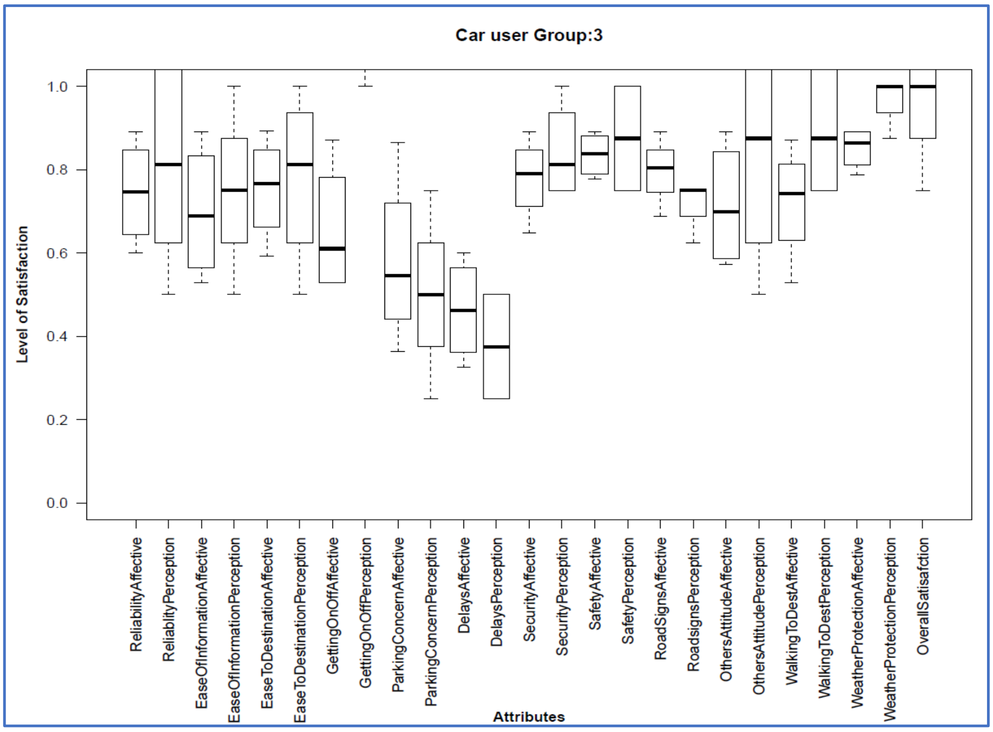


Figure F 4: Boxplot for Car user group 3

F4: The Textual Analysis of Car Users' Concerns

Table F 2 listed the car mode investigated areas, the car users concerns in making journeys to the university and the suggested solutions to address the concerns. The information provided in the table indicates that car users are more concerned about the *delays* and *journey time* due to traffic jams that occur at the junctions. There are also concerns about the limited *parking space* and *high parking fees* within the university as well as the need to have access to real-time information about traffic flow in the city. Summarily, the car users' concerns are categorised into *reliability, journey time, Costs and value for money, comfort* and *convenience* aspects of values and priority measures.

Table F 2: The Textual analysis of Car users' response

The aspects being investigated	Identified problems / Problem sub-category	Suggested Solution space	Related Defined Theme (criteria to measure performance)
Ease of accessing Information	-No real-time traffic information to check traffic situations on specific routes around the city	-Real-time up-to-date traffic information on all route within the city could assist in the planning process.	-Journey-time
Reliability of available information	-	-	-Reliability
Ease of getting to the destination on time	-Running into traffic jam often at the junctions during peak hours	-Real-time up-to-date traffic information on all route within the city could assist in the planning process.	-Journey-time
Parking Space concern	-Insufficient parking space, (when arrived late) people park their cars in distance walk to final destinations. -Parking fees in the University environment is too high.	-More parking spaces -Downward review of parking fee	-Convenience -Costs and Value for money
Delays	-Diversions due to road constructions within the city caused a lot of delays; -Set out early to make for the delays due to peak hour rush, and kid's schools. -No information to motorists on time or beforehand when there are crashes -Delays due to queue at traffic lights	-Real-time information about diversions within the city should always be made available. - The road should be made wider as obtained in other places (e.g. USA) so that more vehicle can flow once the light releases the hold-up	-Journey-time -Reliability
Availability of Road signs	-	-	-
Attitude of other road users	- Some road users drive poorly	-Sensitisation and campaigns on the need to ensure road safety always	-Safety -Comfort
Walking from the main mode to destination	- Due to limited parking space.	- Provide more parking space	-Convenience
Protection from bad weather		-	-

Appendix G: The Rule Base for the CMA Expert Knowledge

```
package moshproject.fuzzycollections;
/* SimpleT1FLS.java, adapted from Juzzy (Wagner, 2012)
 * A simple example of a type-1 FLS based on the "Circumplex Model of Affect"
 * There are two inputs: pleasantness and arousal values.
 * we would like to generate the corresponding affective value.


public class AffectiveGenerator {

        T1_Rulebase rulebase; // the rulebase captures the entire FLS
        double satisfactionValue;
        double importanceValue;

// create a new excel sheet for data reading
        AffectiveExcelReader reader = new AffectiveExcelReader();
        List<AffectiveComponent> newList;
        List<Double> affectiveList = new ArrayList<Double>();

// Read the survey data;
        public AffectiveGenerator() {
                String excelFilePath = "src/AffectiveProperties.xlsx";
                //ExcelReaderExample3 reader = new ExcelReaderExample3();
          try {
                        newList = reader.readPropertiesFromExcelFile(excelFilePath);
                } catch (IOException e) {
                        // TODO Auto-generated catch block
                        e.printStackTrace();
                }

// Define the inputs
        pleasantness = new Input ("Pleasantness Level", new Tuple(-1,1)); // a rating given by a
        person between -10 and 10
        arousing = new Input("Arousing Level", new Tuple(-1,1)); // a rating given by a person
        between 0 and 10

        affective = new Output(" Emotional Affective Level", new Tuple(-1,3)); // a percentage for
        the tip

// Set up the antecedents and consequents - note how the inputs are
// associated...
T1_Antecedent unPleasant = new T1_Antecedent("Unpleasant", unPleasantMF, pleasantness);
T1_Antecedent fairlyUnPleasant = new T1_Antecedent("FairlyUnpleasant", fairlyUnpleasantMF,
pleasantness);
T1_Antecedent neitherPleasantNorUnPleasant = new
T1_Antecedent("NeitherPleasantNorUnpleasant", neitherPleasantNorUnpleasantMF, pleasantness);
```

```
T1_Antecedent fairlyPleasant = new T1_Antecedent("FairlyUnpleasant", fairlyPleasantMF,
pleasantness);
T1_Antecedent pleasant = new T1_Antecedent("Pleasant", pleasantMF,pleasantness);
///
T1_Antecedent unArouse = new T1_Antecedent("Unarouse", unArouseMF,arousing);
T1_Antecedent fairlyUnarouse = new T1_Antecedent("FairlyUnarousing", fairlyUnarousingMF,
arousing);
T1_Antecedent neitherArouseNorUnarouse = new T1_Antecedent("NeitherPleasantNorUnpleasant",
neitherArouseNorUnarouseMF, arousing);
T1_Antecedent fairlyArouse = new T1_Antecedent("FairlyArouse", fairlyArouseMF, arousing);
T1_Antecedent arouse = new T1_Antecedent("Arouse", arouseMF, arousing);

//Consequent-Very Pleasant Experiences
T1_Consequent excited = new T1_Consequent("Excited", excitedMF, affective);
T1_Consequent enthusiastic = new T1_Consequent("Enthusiastic", enthusiaticMF,affective);
T1_Consequent pleased = new T1_Consequent("Pleased", pleasedMF, affective);
T1_Consequent contented = new T1_Consequent("Contended", contentedMF, affective);
T1_Consequent relaxed = new T1_Consequent("Relaxed", relaxedMF, affective);

/// Consequent Fairly Pleasant Experiences
T1_Consequent stimulated = new T1_Consequent("Stimulated ", stimulatedMF, affective);
T1_Consequent elated = new T1_Consequent("Elated", elatedMF,affective);
T1_Consequent happy = new T1_Consequent("Happy", happyMF, affective);
T1_Consequent comfortable = new T1_Consequent("Comfortable", comfortableMF, affective);
T1_Consequent calm = new T1_Consequent("Calm", calmMF, affective);

/// Consequent Neither Pleasant Nor unpleasant Experiences
T1_Consequent afraid = new T1_Consequent("Afraid ", afraidMF, affective);
T1_Consequent anxious = new T1_Consequent("Anxious", anxiousMF,affective);
T1_Consequent neutral = new T1_Consequent("Neutral", neutralMF, affective);
T1_Consequent fatigued = new T1_Consequent("Fatigued", fatiguedMF, affective);
T1_Consequent depressed= new T1_Consequent("Calm", depressedMF, affective);

/// Consequent Fairly unpleasant Experiences
T1_Consequent angry = new T1_Consequent("Angry ", angryMF, affective);
T1_Consequent frustrated = new T1_Consequent("Frustrated", frustratedMF,affective);
T1_Consequent dissatisfied = new T1_Consequent("Dissatisfied", dissatisfiedMF, affective);
T1_Consequent uncomfortable = new T1_Consequent("Uncomfortable", uncomfortableMF,
affective);
T1_Consequent bored= new T1_Consequent("Bored", boredMF, affective);

/// Consequent Unpleasant Experiences
T1_Consequent disgusted = new T1_Consequent("Disgusted ", disgustedMF, affective);
T1_Consequent discontent = new T1_Consequent("Discontent", discontentMF,affective);
T1_Consequent disappointed = new T1_Consequent("Disappointed", disappointedMF, affective);
T1_Consequent sad = new T1_Consequent("Sad", sadMF, affective);
T1_Consequent dejected= new T1_Consequent("Dejected", dejectedMF, affective);
```

```
// Set up the rulebase and add rules
rulebase = new T1_Rulebase(25);
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { pleasant, arouse }, excited));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { pleasant, fairlyArouse }, enthusiastic));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { pleasant, neitherArouseNorUnarouse },
pleased));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { pleasant, fairlyUnarouse }, contented));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { pleasant, unArouse }, relaxed));
///
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyPleasant, arouse }, stimulated));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyPleasant,fairlyArouse }, elated));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyPleasant,neitherArouseNorUnarouse },
happy));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyPleasant,fairlyUnarouse }, comfortable));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyPleasant, unArouse }, calm));

rulebase.addRule(new T1_Rule(new T1_Antecedent[] { neitherPleasantNorUnPleasant, arouse },
afraid));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { neitherPleasantNorUnPleasant, fairlyArouse
}, anxious));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { neitherPleasantNorUnPleasant,
neitherArouseNorUnarouse }, neutral));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { neitherPleasantNorUnPleasant,
fairlyUnarouse },depressed));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { neitherPleasantNorUnPleasant, unArouse },
fatigued));

rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyUnPleasant, arouse },angry));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyUnPleasant,fairlyArouse },frustrated));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyUnPleasant, neitherArouseNorUnarouse
},dissatisfied));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyUnPleasant,fairlyUnarouse
},uncomfortable));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { fairlyUnPleasant,unArouse },bored));

rulebase.addRule(new T1_Rule(new T1_Antecedent[] { unPleasant, arouse },disgusted));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { unPleasant,fairlyArouse },discontent));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { unPleasant, neitherArouseNorUnarouse
},disappointed));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { unPleasant,fairlyUnarouse },sad));
rulebase.addRule(new T1_Rule(new T1_Antecedent[] { unPleasant,unArouse },dejected));
}
```

Appendix H: A Novel Modal Shift Modelling Framework for Transport Systems

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Abstract

The challenges from transport modes on human environments, health and economy, have called for investigations into how behavioural changes can be achieved for better resource utilisation. Trip makers' travel demands have been identified, and they include cognitive, physical and affective aspects. Presently there is a shortage of models that integrate all those demands. In addition, trip maker's context during decision making and social interaction structures are not addressed. These gaps have made it difficult to stimulate behavioural changes for modal shift effectively. This paper introduces a novel MOdalSHift framework (MOSH framework) to support research on how to best stimulate trip makers' behaviour changes to adopt less preferred transport modes. MOSH framework encompasses the Consumat model, which integrates social-psychological theories, coupled with a cognitive work analysis. These two (consumat and cognitive work analysis) were chosen to incorporate all travel demand factors into trip maker's decision-making process. A hypothetical case study model of the shift from road to rail was developed using the framework to demonstrate its applicability for such investigations.

Keywords: Modal Shift, Modelling, Transport System, Consumat, Cognitive work analysis.

1 Introduction

Human activities and their lifestyle have impacted negatively on the ecosystem to such an extent that its existence is threatened. Prominent among these activities is the transport system. A transport system consisting mainly of road, rail, air and waterways is fundamental to growth in an industrialised society. Transport sector according to Stanton (2013) remains the fastest-growing, and it is characterised with environmental, economic, social and health challenges.

Stakeholders have approached these challenges using different world-views, which include technological innovations, expansions and construction of new road links and policy initiatives, such as advocating for individual behavioural change. While some of these approaches can be capital intensive and subject to limitations Steg (2007), a behavioural change approach towards a mode of transport shift can be achieved with less costs and provide immediate impacts on curbing the challenges (Chapman2007; Steg 2007; Roberts *et al*. 2014). However, insights into the usefulness and effectiveness of these approaches could be gained through model representations.

There are a plethora of models for studying trip maker's mode choice. There is, however, shortage of models for behavioural change in modal shift. Modal shift as described by Rodrigue (1998)occurs when a transport mode has a comparative advantage in a similar market over another mode. Hence, the mode with better advantage attracts more users than the other. To our knowledge, most mode choice models available have centred on the modal split, which looks at the proportion of passengers using a particular transport mode. These models are not useful for policymakers who wish to understand the motives behind trip maker's mode choice behaviours. Hence, to achieve behavioural change, several factors that drive trip maker's behaviour in mode choice have to be considered for proper stimulation of behaviour towards the desired mode.

In order to contribute to overcoming those limitations, we introduce a novel MOdalSHift (MOSH) framework that captures the nonlinear and heterogeneous characteristics of trip makers. The characteristics include aspects such as their cognitive, physical and affective differences during mode choice decision-making process. MOSH framework aims at providing modelling techniques that allow investigations into individual actor's attributes, behaviour and interactions. The application of MOSH framework is demonstrated through a hypothetical case study, focussing on the modal shift from road to rail. In this case study, we employ agent-based modelling to explore the autonomous features of individual agents and observe the emergent behaviour arising from their interactions. We were able to observe that the model conceptualised from the framework is capable of assisting policymakers to gain insight into modal shift problems and provide guides on how to effectively stimulate their behaviours.

The remainder of the paper is organised as follows: Section 2 discusses the background to the study which includes research on modal shift, factors and constraints to modal shift, approaches to modelling mode choice, and agent-based modelling. Section 3 gives the overview, explain the components and process flow of the MOSH framework. A hypothetical case study to address a specific modal shift problem is developed and implemented as presented in Section 4. Finally, Section 5 presents the conclusions and proposes further ideas for future research.

2 Background

2.1 Modal Shift

Several studies conducted on modelling mode choice have focused on the modal split (e.g., Sakano & Benjamin (2011), Nurdden *et al*., (2007)). These models are non-behavioural and employ aggregate approaches which are only good for planners and engineers to make predictions (Barff *et al*. 1982) and not for understanding factors responsible for individual mode choice. Moreover, the majority of modelling studies available on modal shift have mainly been on freight and shipping transports (e.g., Islam *et al.,* 2016; Blauwens *et al.,* 2006). There are few available models on passengers' travel patterns. Most of these few models based their behavioural architecture on limited socio-psychological theories of human behaviour. For instance, Heath & Gifford (2002) use the theory of planned behaviour to predict the use of public transport hence, failed to represent human behaviour adequately.

2.2 Factors and Constraints to Modal Shift

Social, psychology and human factors researchers have been at the centre of studies on constraints to mode choice. Wardman *et al*. (2001) broadly conceptualised travel demands in terms of physical ability, cognitive efforts and affective (i.e. the subjective emotional assessment of individual circumstances) required to make a trip. In addition, some utility factors such as cost and value for money, punctuality and reliability, frequency of the mode, comfort/cleanliness, travel time, bus stop/interchange/station facilities, etc. have been identified in several studies (e.g. Derek Halden Consultancy (2003), DfT (2009)) as major constraints preventing car travellers from shifting to other modes. These factors have also been identified in social and psychology studies to have consequences on travel demands. Mann and Abraham (2006) observed that utility beliefs influence decisions through their affective impact.

Attitudes and perceptions in addition to the utility factors have also been investigated. Atasoy *et al*. (2012) and Chee & Fernandez (2013) incorporated these two factors into the mathematical models presented in their studies to investigate mode shift problems. Apart from the factors mentioned, other modal shift constraints with significant effects are experiential and personal affective. Gardner and Abraham (2007) and Mann and Abraham (2006) found out that journey-based affect and personal space/autonomy are common affective barriers in mode shift to public transport. In a recent study, Ryan *et al*. (forthcoming) used thematic analysis method to understand the functional and affective aspect of a commuters' journey to a university using Herzberg's Hygiene-Motivation theory. Their study revealed some motivational factors (e.g., a sense of being valued as a passenger; excitement in the journey), and hygiene factors (such as rule and policies; impact on personal status) as factors that affect mode choice. Also, Ryan study confirmed Stanton *et al*., (2013) system based analysis findings, which state that there are interrelationships between constraints that impact on mode choice and travel decisions.

From our point of view, and as revealed in the literature on constraints to modal shift, it is clear that effective modelling of modal shift problems requires a complete representation of travel demand factors as identified by social, psychology and human factors studies. At present, this not easily achievable because most of the existing models' behavioural architectures were based on few socio-psychological theories of human behaviour, and are implemented using mathematical approaches. Recent studies including Osman Idris *et al*. (2015), Tudela *et al*. (2011)) used traditional mathematical choice models such as classical logitDomarchi *et al. (*2008); probit Atasoy *et al*. (2012) and hybrid Temme *et al.*(2007) mode choice models in their studies.These approaches impose limitations on the models' capabilities to include many relevant theories of human behaviour in choice making. Attempts to include all attributes and interrelated features of different passengers would therefore, result in multiple complex equations, which are difficult for non-experts to comprehend. More importantly, social interaction structures among the actors and their immediate environments are not emphasised or explained in the methodologies provided by these models. Furthermore, real-time and dynamic observations of trip makers' behaviour are not possible due to the static nature of the mathematical approaches. Therefore, to address these limitations, an agent-based modelling technique is explored in this study.

2.3 Agent Based Modelling

Agent-based modelling (ABM) has become a widely used technique to model complex systems composed of interacting, autonomous "agents" (Charles M Macal & North, 2010). Agents have behaviours, interact with and influence each other, learn from their experiences, and adapt their behaviours. Furthermore, individual modelling of agents allows full effects of the diversity that exists among agents with respect to their attributes and behaviours to be observed. Individual agents disaggregate behaviour within an environment give rise to emergent and observable system effects. The features provided by this technique will be explored in this study.

As revealed in the reviewed literature, the existing mode choice models lack the capabilities to achieve the objective of stimulating trip makers' behaviour for the mode shift due to the following limitations:

- There is no reference to trip makers' context (situation) during decision-making process
- Existing models are often purely mathematical and hence, give limited room for actors' multiple and heterogeneous characteristics to be observed
- The effect of social interactions among individuals and with the environment is not emphasised
- There are no clues provided on how trip maker behaviour can be stimulated to encourage modal shift

To effectively address the problems highlighted, a framework is introduced in the next section that presents a new methodology for dynamic and comprehensive investigations into various trip makers' features and mode choice factors.

3 The MOSH Framework

3.1 Overview

The focus of this framework is to provide support for understanding how best to stimulate individual trip makers' behaviour, to enable them to adopt less preferred but greener modes of transport as a result of mode usage challenges on human lifestyle. It considers the heterogeneity in trip makers' physical, cognitive and affective characteristics and accounts for actors' context in the process of trip making within an uncertain and dynamic socio-technical system.

To achieve this, our proposed modal shift framework (depicted in Figure 1) brings together integrated theories of human behaviour in choice-making and human factors' formative task analysis models.

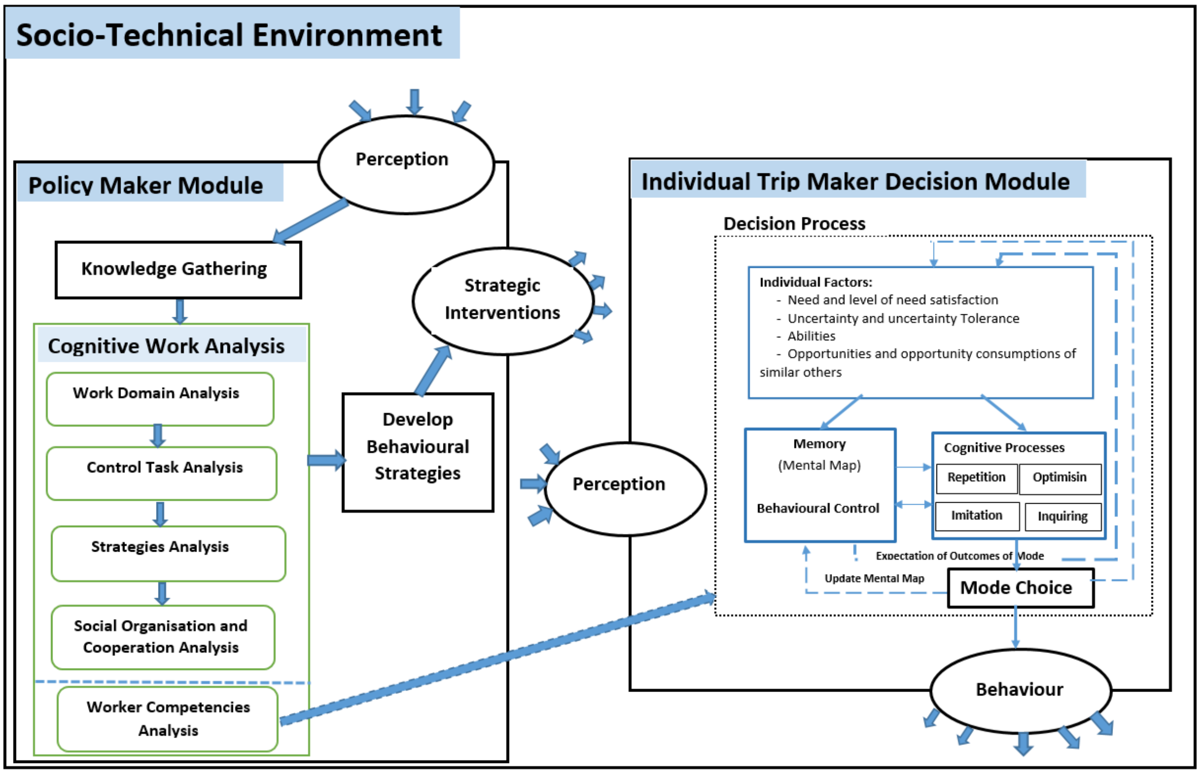

Figure 1: Modal Shift (MOSH) Framework (inspired by Jager and Janssen, 2012; Jager, 2000; Rasmussen *et al*., 1994; Vincente, 1999; Schlüter *et al.,* 2017)

The framework consists of three major components: The outer box in the figure represents the **socio-technical environment**. It consists of technology, economy, demography, cultures, institutions, within which the two inner boxes (policymakers and individual trip makers) operate. According to Jager (2000), the sociotechnical environment is a human-induced environment that is derived from and operating within the larger natural environment. Sociotechnical resources are available and are applicable to all actors within the system irrespective of status, thereby making the environment the decision context of actors.

The **policymaker module** consists of three activities: *Knowledge Gathering*, *Cognitive Work Analysis (CWA)*, and *Develop Behavioural Strategies*, and two processes: *Perception* and *Strategic Interventions*. The CWA is a well-established human factors formative task analysis tool developed by Rasmussen *et al*. (1994) and Vincente (1999). It focuses on how human-system interactions are conducted within a given domain, rather than how it currently works or how it should operate. CWA allows policymakers to gain insights into those factors influencing trip makers' behaviour and their relationships. The activities and processes in the diagram are connected with solid arrows indicating the flow of information.

The **Individual trip maker decision module** centres on the "Consumat" approach. Consumat is a well-researched and cognitively-inspired conceptual model that integrates several known social-psychological theories. It was developed originally by Jager (2000) to model consumer behaviour and market dynamics; it was later revised by Jager and Janssen (2012) to accommodate more realistic behaviours in choice making. Consumat provides our framework with social-oriented heuristics, possible network structures for agents' interactions and cognitive processes in human decision making.

3.2 Components of the MOSH Framework

The challenges of transport systems on various aspects of human life lead stakeholders to the process of fact-finding (knowledge gathering) their causes. The outcome of the knowledge gathering is further analysed with CWA, which is a five-phased framework that focuses on how system constraints limit functionality in specific situations within a socio-technical system. Most of the illustration on the description of CWA in this section is obtained from (Stanton *et al*., 2013). Following is a detailed description of the different phases of the CWA framework:

- *Work Domain Analysis (WDA):* Uses its abstraction hierarchy (AH) shown in Figure 2 to provide investigative access to the system's components and environments at different levels of granularity (refer to Jenkins *et al*., (2009) for details). In our case, the WDA reveals the fundamental set of constraints that the modes' components, the process of using the components and their purposes impose on the actions taken by the trip makers. The AH describes a system based on five different levels, ranging from physical objects (the physical components of the system) at the bottom, up to overriding functional purpose at the top(the system's reason for existence). It makes use of the 'why-what-how' triad to provide guidance by giving answers to why the system exists, what functions can be conducted within the domain as well as how these functions can be achieved. Figure 2 shows an extract from a larger AH. For instance, provisions of 'what' communication facilities can be derived from 'how' access to telephony network while onboard. These two (i.e. what and how) answer the question of 'why' cater for needs of the trip maker. Investigators may be interested in asking and answering questions at any level of these details.

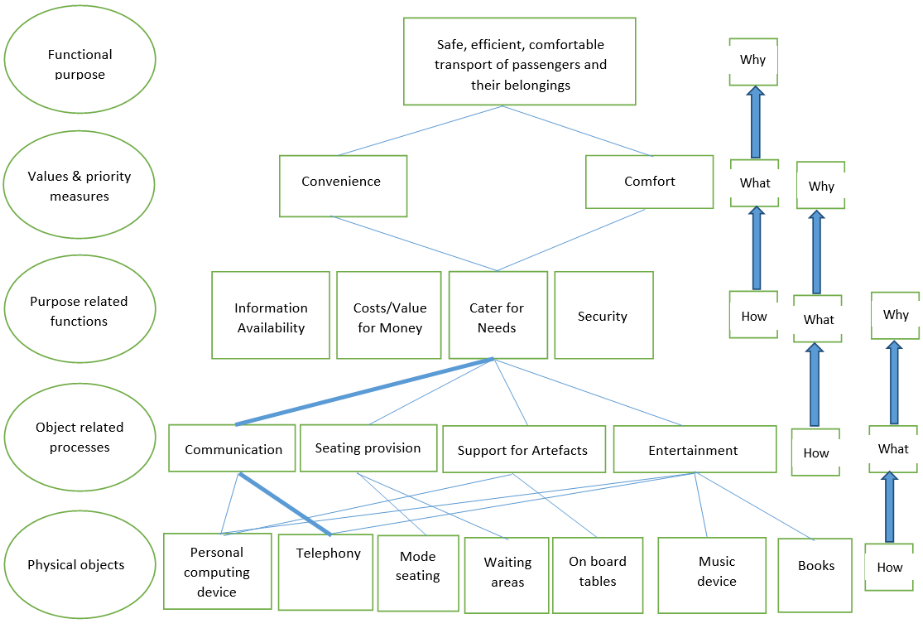

Figure 2: Work Domain Analysis (Abstraction Hierarchy): An example

- *Control Task Analysis (ConTA)*: Accounting for the decision maker's context is one of the gaps this framework sought to address. Hence, the ConTA is an important phase that models the context of the trip maker. It uses contextual activity templates (CAT) introduced by Naikar *et al*. (2006) (see Figure 3) to model known recurring activities within the system. It focusses on which activity can be achieved independently of how it is conducted or who undertakes it. Constraints to performing a required activity have a significant influence on the decision- maker. For instance, on a long-haul train journey, connections with telephone network are an issue for a trip maker who needs to be in constant touch with business partners or for other purposes. Consequently, in the contextual activity template for a rail user example shown in Figure 3, situations are placed in the horizontal axis representing various stages of a trip maker's journey. These situations are subsequently mapped to functions that occur under each situation. A function in this context is the activity a user can perform in a given situation. Functions are taken from object-related processes of the AH (see the second row of figure 2) and form the vertical axis of the templates. The cells with ball and whiskers in the template indicate situations where functions can and typically do occur; while cells surrounded by dotted line indicate the function is able to occur in this situation but typically does not, and Empty cells without ball or dotted lines indicate the function is not possible in that situation.

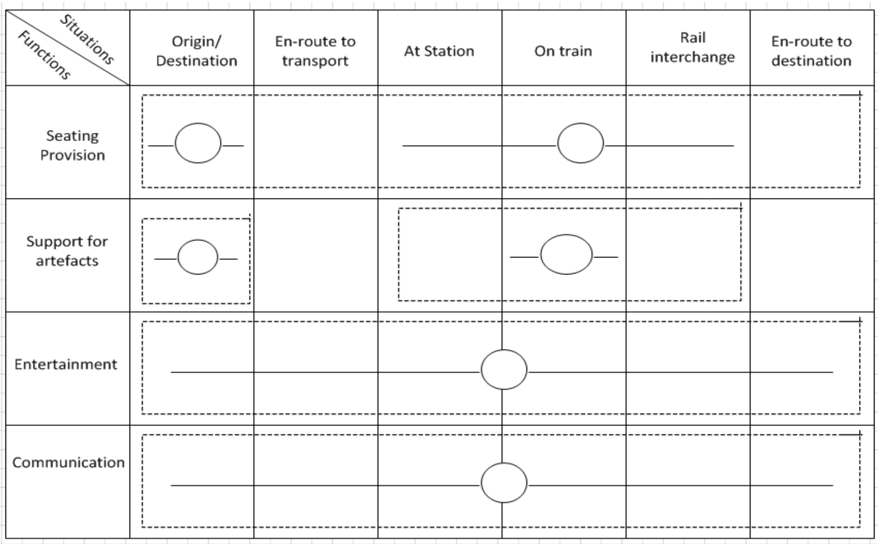

Figure 3: Contextual Activity Template for the rail system (Source: Stanton *et al*., 2013)

With the information provided by the template, policy-makers can make provisions for situations where functions can be performed but are not yet adopted.

- *Strategies Analysis (SA)*: There are different ways to carry out the same activity by the trip makers. SA looks at known recurring activities as presented in CAT and considers different strategies that are likely to be used to complete them. For instance, to ensure constant communication networks in a long-haul train travels, wireless technologies can be installed on the train coaches. While CTA focuses on what needs to be done, SA focuses on the flexibility of doing it in different ways, in that context. The freedom and flexibility allow the user to adapt and select a way of achieving an end-state that is most appropriate in a given situation.
- *Social Organisation and Cooperation Analysis (SOCA)*: Focuses on constraints imposed on individual trip maker's needs and requirements. It indicates where each trip maker can perform a given function rather than where they typically perform or should perform the function. For instance, a mobility-impaired trip maker may not have the same flexibility in accessing a train as an abled bodied trip maker. SOCA uses CAT to show how each of the functions and situations can be examined with respect to individual differences (e.g. physical, cognitive abilities, etc.).

The outcome of the first four phases (i.e., Focussing on what activity can be achieved independent of how it is conducted or who undertakes it; strategies that are likely to be used to complete the activities; and identifying individual trip maker limitations in using the mode) gives the policy-maker enough insights about the system and various trip maker possible stereotypes. Hence, assist in the "Develop Behavioural Strategies" activities stage to establish new strategies to extend the system flexibility. The results of the strategies are presented as interventions into the environment.

- Worker Competencies Analysis (WCA): Lastly, the skill level needed by a trip maker to effectively choose a suitable mode for the trip is determined at this stage. This skill is a function of individual cognitive, physical, tolerance and affective capabilities. The activities within this analysis stage are mapped to and detailed in the decision process of the *Individual Trip Maker Decision Module as* depicted in Figure 1.

The second inner box in Figure 1 named *Individual Trip Maker Decision Module* consists of two states and two processes. The states are the *Decision Process* and the *Mode Choice,* while the processes are the *Perception* and the *Behaviour*. The *Decision Process* contains three boxes including (i) *Individual Factors,* which are the decision making driving factors. (ii) The *Memory* and *Behavioural Control* that consists of the trip maker's own characteristic, previous experiences of using various modes, available mode's characteristic, and similar others experience; as well as the ability has by the trip maker, and the ability demanded (physical, cognitive, and affective) to make the trip. And (iii) possible *Cognitive Processes* the trip maker adopts in selecting a mode. The two dotted lines within the decision process box represent the updating and evaluation processes. The outer dotted box updates the memory with the trip experience, and the inner one evaluates how well the mode meets user's expectation. The solid lines are the flow of information between the major states.

3.3Process Flow through the MOSH Framework

The process flow diagram in Figure 4 provides a guide to understand the framework better. Processes and decisions in the diagram are labelled with numbers. To make a trip, an individual has certain personal characteristics and journey purpose which influence the choice of mode for the journey (elements 2 and 3 in Figure 4). The decision for mode choice is determined by the individual driving factors which refer to the trip maker's internal state; behavioural control; and memory contents.

The decision making is based on the ratio of trip maker's *Level of Need Satisfaction and Aspiration Level* (LNS/AL), and/or *Behavioural Control* (BC) with the ratio of *Uncertainty and Uncertainty Tolerance* (U/UT). The outcome of which determines the engagement of trip maker in any of the four cognitive processes of *Repetition, Optimising, Imitation,* and *Inquiring* (elements 7,9,13 and 15 in Figure 4).

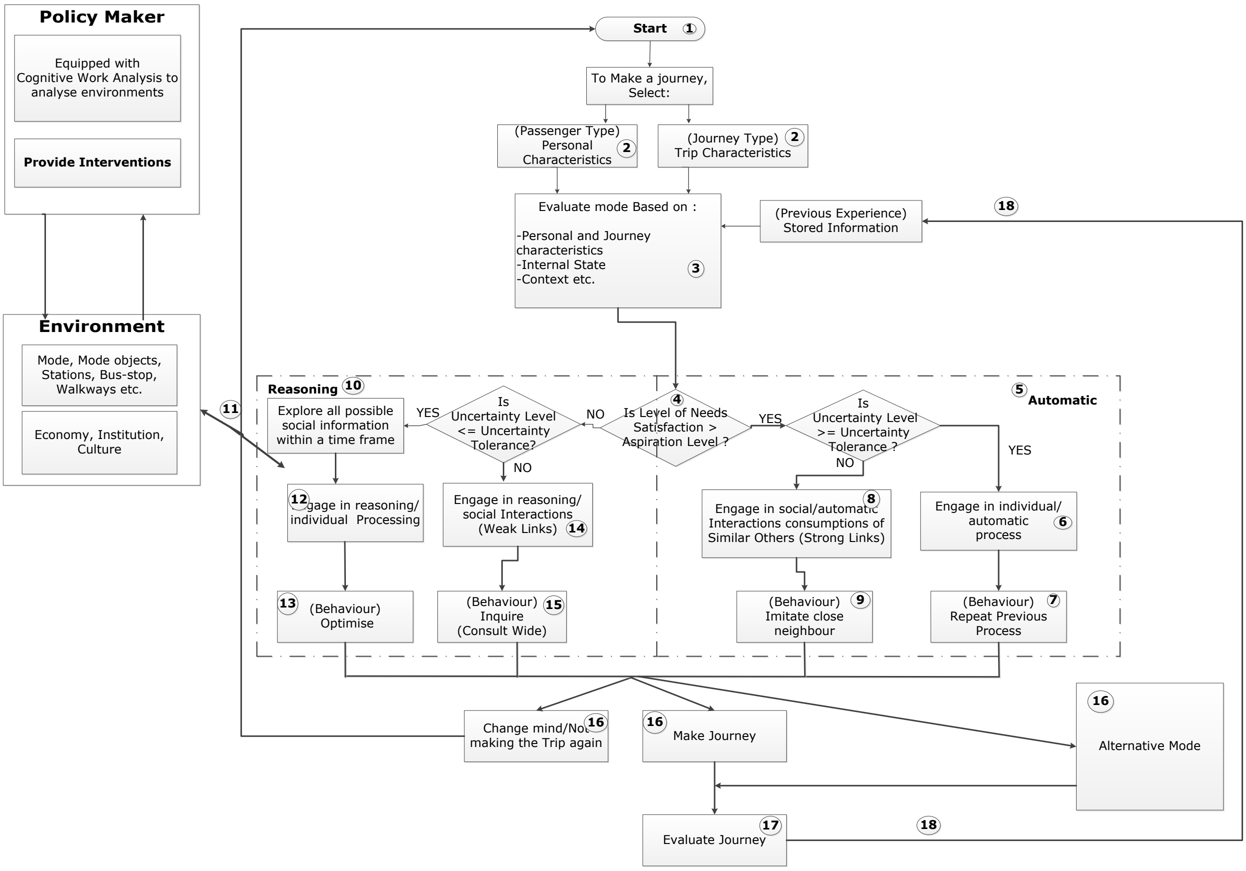

Figure 4: Modal Shift Process Flow

Cognitive processes are identified along two dimensions of *reasone*d versus *automatic* (elements 5 and 10 in Figure 4) and *individua*l versus *social* (elements 6, 8, 12, and 14 in Figure 4). A trip maker engages in individual behaviour when its level of uncertainty is low (i.e. U<UT), and engages in social when uncertainty is high (U>UT). The automatic process occurs when its preferred mode of transport regularly satisfies its need. Automatic behaviour can be individually or socially executed; it is individual when a trip maker *repeats* previous ways of making trips without consulting others or engaging in the cognitive evaluation. It is social when other similar trip makers are *imitated.* However, *reasoning* processes occur when there is dissatisfaction i.e. (LNS<AL or/and BC<=0). Then, the trip maker would need to elaborate on alternative travel modes in order to make the journey. This process can also be individually or socially executed. It is individual when reasoned within itself by making use of information from the environment to deliberate on the mode to use; it is social when a trip maker consults similar and non-similar other trip makers in order to find better alternatives. At some points during the reasoning process, individual trip maker consults the environment for more information among other means. In the process, it encounters any improvements or nudges provided by the policymaker through the insight gained from analysing the system. This may affect its ability required to make use of the desired mode and hence, affect either its behavioural control or level of need satisfaction.

Lastly, when a mode is chosen and the trip made, the aggregated effects of individual trip makers' behaviour in mode usage go back into the environment. The trip maker's perception of the environment is represented by the equation below:

$$P(it)=\emptyset U_{it}^{(\propto 1)} * \alpha F_{it}^{(\propto 2)} * \gamma O_{it}^{(\propto 3)}$$

Where:

- P is the perception based on the change in environment at time t for mode i
- U is the improvements perceived on utility factors, and ∅ is the coefficient of the improvements for mode i.
- F is the improvement perceived on psychological factors, and α is the coefficient of improvements for mode i
- Ois the improvements perceived of other factors (cognitive, physical, etc.) and γ is the coefficient of improvements for mode i
- ∝ is the Cobb-Douglas type utility weighted function (Janssen & Jager, 1999) to factor the perception such that the quantity of each factor contributes to the total perception.

4 A Hypothetical Case Study

In the following, we use the MOSH framework to conduct a hypothetical case study for modelling and simulating road to rail shift. This will help to demonstrate the feasibility and applicability of the framework.

4.1 Case study description

For this case study, we assumed the "perception" process and "knowledge gathering" stage of the MOSH framework had been undertaken before the generation of data made available to us by the UK National Rail Passenger Survey (Transport Focus, 2016) detailed in section 4.4.

In this case study, there is a given population of heterogeneous passengers with many attributes including the purpose of the journey, the category of passenger, disabilities and demographics.

4.2Model Design

In the model design, some assumptions and simplifications are made. The assumptions include: there are differences between the expected satisfaction and the actual satisfaction levels from a mode; limited mode's attributes considered in this model provide enough insights regarding the functionality of the model. While the simplifications are: distance travelled by the passenger to the nearest bus stop and the train station as well as period to go out and come back are not modelled; all transportation system run 24 hours a day. The simplification is to keep the model simple, while still maintaining satisfactory results and reasonable outputs from the model design.

The considered mode's attributes are obtained from the purpose related functions level in the WDA of the cognitive work analysis (see the middle row of Figure 2). The attributes (cater for need, security, information availability, and costs/value for money) are chosen to enable incorporation of passengers' physical, economic, cognitive and affective views of a mode.

Cater for need is about how well the transport mode satisfies the needs of trip makers. While the Security assesses how safe is the mode at the time of the trip. Information availability focusses on the ability of a passenger to access needed information at any point of the trip. Cost/Value for money attribute is an economic and utility variable that has strong effects on trip maker's decisions. Each of the mode's attributes is appropriately evaluated based on users' level of need satisfaction, this is represented by index varying between 0 (fully unsatisfied) and 1 (fully satisfied), as shown in the equation below:

LNS_t=LNS_1t^(∝1)*LNS_2t^(∝2)*LNS_3t^(∝3)*…*LNS_nt^(∝n)

Where:

- LNSit is the level of need satisfaction for need i at time t
- ∝is the Cobb-Douglas type utility weighted function that factors the total level of individuals need satisfaction such that the quantity of each of the needs contributes to the total LNS (Janssen and Jager, 1999).

The passenger's cognitive and user experience behaviours are captured by the state machine diagrams in Figures 5 and 6 respectively. A state machine diagram captures the different states of an entity as well as the possible transitions between these states. For more information about state machine diagrams (see Bersini (2012); Siebers & Onggo (2014)). In Figure 5, a trip maker can be in any of the four cognitive states shown in the diagram (repetition, optimising, imitation, or inquiring) depending on the determining factors (the ratios of LNS/AL, BC, and U/UT). Figure 6 shows the adoption transitions pattern from car to train. The inner single state on the left shows a trip maker as a car mode user, while the inner composite state on the right side of the figure shows a trip maker as a Train user. Each state within the Train Users Experience state represents a class of train usage.

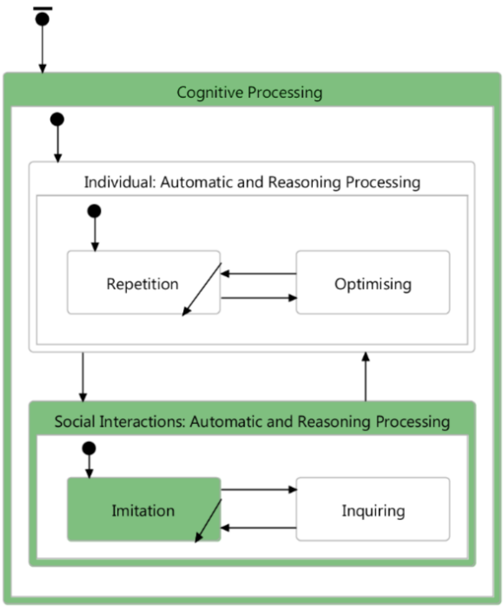

Figure 5: Passenger Agent: Cognitive Processing State Machine Diagram

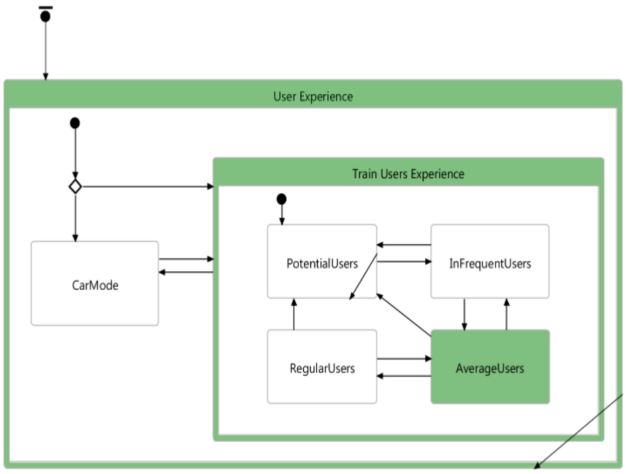

Figure 6: Passenger Agent: User Experience State Machine Diagram

4.3 Implementation of the Model

The model was simulated in the Recursive Porous Agent Simulation Toolkit (REPAST) Simphony version 2.3.1. REPAST is a free, open source, and Java-based simulation toolkit for ABM. There are three classes of active objects in the simulation: the passenger, the mode, and the policymaker.

Two stereotype categories are considered for the passenger agent, "the passenger type" and "the user experience level". The passenger type includes old age pensioner, youth, able-bodied person, and family. Each embarks on different kinds of journeys which include commuting (education, apprentice, and work), leisure (holiday, shopping, visiting) and business. There are also different levels of journey familiarity for various passengers based on journey types. The user experience stereotype has passengers as road users who have no rail usage experience and rail users with different level of rail usage experiences such as potential users, infrequent users, average users and regular users (Figure 6). The two travel modes modelled are car and train. The car is considered to be the highly preferred mode and train as the less preferred mode.80% of the population are car users, while 20% are train users. The policymaker agent develops and provides interventions to improve the passenger's experience. Passenger satisfaction is focused on each of the four mode's attributes mentioned in the model design (Section 4.2).

A population of 6700 passengers is simulated, which is distributed as follows: 2500 able-bodied adults, 1000 families, 2000 youth, and 1200 old age pensioners. The simulation runsfor a period of240-time steps (where one model time step is equivalent to one hour in a continuous model). The uncertainty tolerance and aspiration level are randomly generated. Passengers 'initial experience' is set to zero for all the mode attributes at time t=0. Social agreeability is calculated based on social settings given as follows: the maximum allowed difference between interaction initiator (interactor) and the chosen partner (interactee) is set to 0.5. Two interacting passengers with a maximum difference higher than this value are not qualified to interact. Because their level of conformity and similarity (social, previous experience, journey type, etc.) are assumed to have large variations to interacting passengers. The social interaction is set to 2% of the entire population. The above settings are based on informed guesses made through consultation with experts in rail transport research and agent-based simulation.

4.4Parameterisation and Validation

The model's variables are calibrated based on the set of descriptive data acquired from the UK's National Rail Passenger Survey (NRPS Spring 2015: Wave 32) (Transport Focus, 2016). The NRPS data is supported by car usage data from the DfT Report on "Understanding the drivers of road travel" (DfT, 2015). Corresponding values from the datasets relevant to our chosen mode's attributes are selected, aggregated (as shown in Table 1) and used for the calibration. In addition, experts in rail passenger research and agent-based simulation are consulted to verify the simulation settings assumptions made. The model is validated at various stages of the simulation using techniques such as independent review, continuous code debugging, model run with known characteristics, and animation.

Table1: Spring 2015: Wave 32 Descriptive Data

Satisfaction level	Information Availability	Cater For Need	Security	Value for Money
Very satisfied	0.26032	0.2666747	0.29843262	0.163797895
Fairly satisfied	0.437919	0.38659769	0.4765658	0.282060143
Neither satisfied nor dissatisfied	0.193382	0.14026273	0.19086208	0.209335071
Fairly dissatisfied	0.073792	0.10339568	0.02196016	0.204737609
Very dissatisfied	0.034587	0.1030692	0.01217934	0.140069282

The values in Table 1 show the percentage of the total population that perceived each of the mode's attributes on the scale ranging from "very satisfied" to "very dissatisfied". The values are used in the simulation. Corresponding output for each of the attributes is observed from the simulation model and recorded as shown in Table 2.

Table 2: Modal Shift Simulation Values

Satisfaction level	Information Availability	Cater For Need	Security	Value for Money
Very satisfied	0.195789326	0.169994382	0.232050562	0.088030899
Fairly satisfied	0.365980337	0.28561236	0.454356742	0.194101124
Neither satisfied nor dissatisfied	0.202598315	0.121174157	0.204617978	0.165044944
Fairly dissatisfied	0.091570225	0.125393258	0.027207865	0.194710674
Very dissatisfied	0.086567416	0.240331461	0.024272472	0.300617978

Following this, a correlation study is carried out on the NRPS data (Table 1) and the simulation model's output (Table 2) for the selected mode's attributes. The result of the comparison is shown in Figure 7 and Figure 8 below.

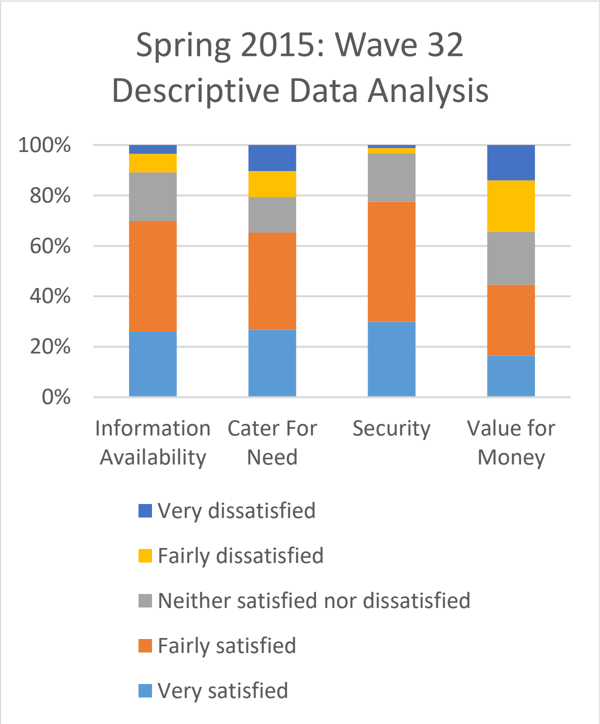

Figure 7: NRPS Descriptive Data (Spring 2015: Wave 32)

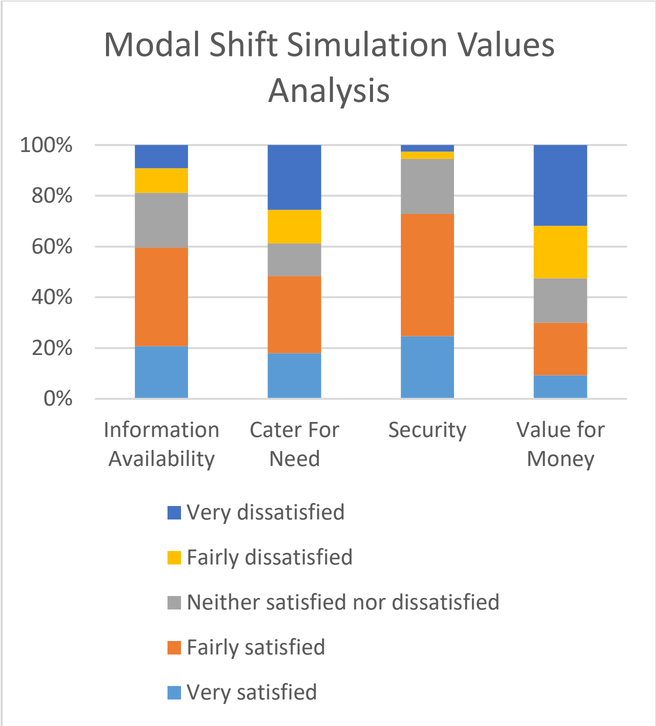

Figure 8: Simulation Model Values

Figures 7 and Figure 8 show strong correlations between each of the corresponding attributes of the descriptive data and the output data of the simulation. However, there are some variations in the "cater for need" and "value for money" attributes, which might be due to the assumptions we made, but for our purpose to demonstrate the application of the framework, the output of the simulation is sufficiently accurate. We will use this simulation result later as our base case result that we are comparing against.

4.5 Experimentation

The following hypothetical experiment should provide some insight into the operation of the simulation. In this experiment, we look at the changes that occur in a passenger's travel mode adoption patterns as well as in their cognitive processes in the process of making travel mode choice. We consider two scenarios:

- Base scenario: employs the output from the validation experiment
- Experimental scenario: investigates behavioural changes as a consequence of providing interventions to reduce car usage. The only intervention provided in this experiment is the introduction of parking space tax policy for car users. The base scenario started without intervention, a parking space tax of £2.5 is introduced at 120 hours, and the behaviour is observed up till 240 hours. Another simulation run based on the same previous settings is carried out, in which parking space tax of £5 is introduced from 120 hours up to 240 hours.

The users' adoption patterns for the two experimental scenario runs are observed and compared with the base scenario output.

4.6Results

The observed outputs from the simulation show a plot of passengers' mode adoption patterns and cognitive processing behaviour depicted in Figure 9 and Figure 10 respectively. The behaviours of the two experiments are observed from time 0 to 240 hours. The simulation runs became stable after 24 hours and remained constant up to time 120 hours when interventions are applied.

The overall stable behaviour from the beginning of the simulation reflects the present situations as captured from the NRPS dataset used for parameterisation. Figure 9 and Figure 10 show the number of adopters (y-axis) against the time steps (x-axis).In the first simulation run shown in Figure 9, a parking space tax policy of £2.5 is introduced at 120-time steps when the numbers of car users and train users are 2967 and 3733 respectively.

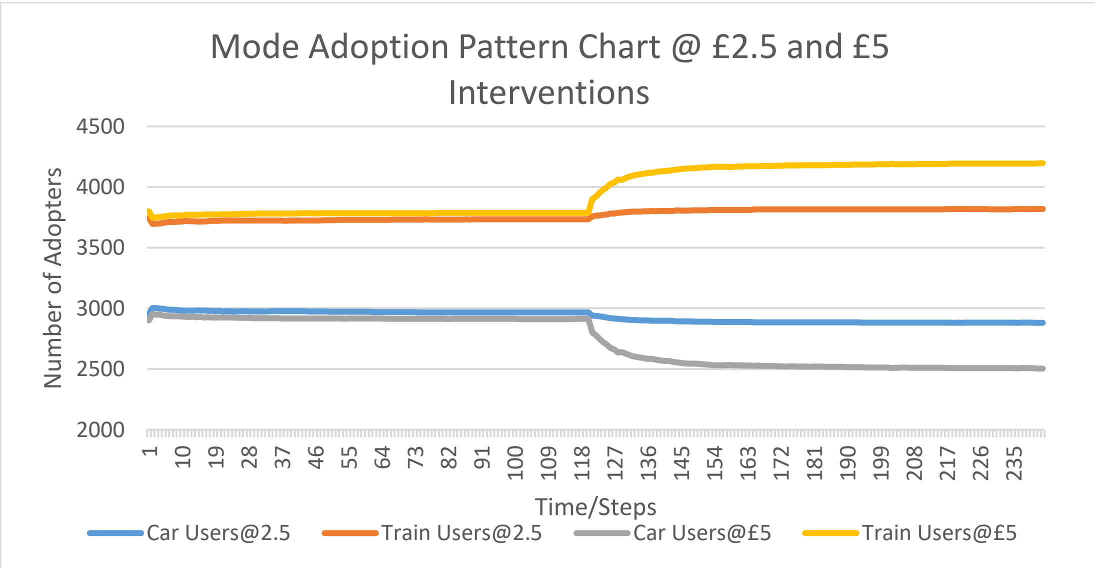

Figure 9: Passengers' Mode Adoption

This intervention gave a slight increase of 2.3% in the numbers of train users at 240 steps when the behaviour became stable again. The number of car users reduced by the same percentage. In the second simulation run also shown in Figure 9, the parking space tax policy of £5 is introduced at 120-time steps as the first run, to allow direct comparison. The numbers of car and train users are 2913 and 3787 respectively. The simulation is observed up to step 240 when the pattern became stable. The output shows that the number of train users has increased by 14.0% while that of the car users has reduced by the same percentage.

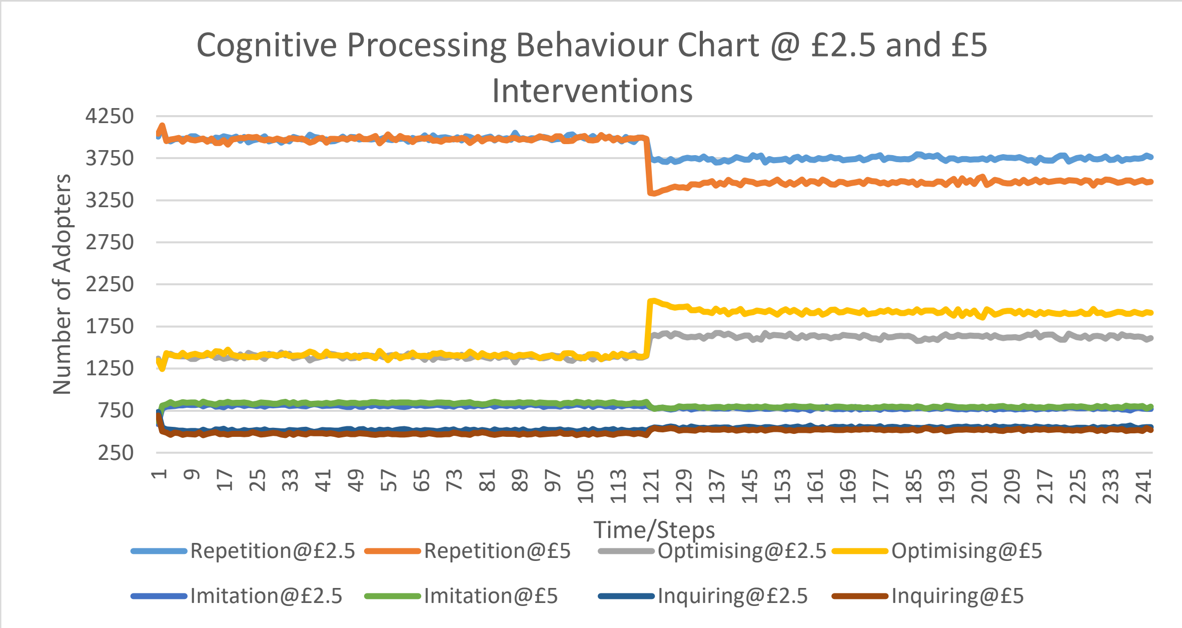

Figure10: Passengers' Cognitive Behaviour

Figure 10 shows the number of passengers engaging in different behaviours before and after the £2.5 and £5 tax policy interventions. Before the interventions are introduced at 120-time steps, the results indicate that 59.5 % of all the passengers are found repeating their previous behaviours (either using car or train as mode). 20.8 % of the passengers are found optimising their behaviour, while 7.6% are engaging in making inquiries about better alternative modes, and the remaining 12.1 % were involved in imitating their happy neighbours. After the interventions have been applied, the simulation is observed at step 240 when the behaviours are found stable. For £2.5 intervention, the percentage of passengers repeating their previous behaviour has reduced by 3.4%, while optimisers have increased by 3.5% and those engaging in inquiring have increased by 0.4% and those engaging in imitation has reduced by 0.4%. For £5 policy intervention, a reduction of 7.5 % is recorded for passengers repeating their previous behaviour, while optimisers have increased by 7.6%; those engaging in inquiring have increased by 0.84% while imitators also reduced by 0.86%.

4.7 Discussion

It was observed from the experiment that the proportion of the number of adopters when £2.5 and £5 tax policies were applied was not linear. With £2.5 parking tax policy, 2.3% car users adopted train transport as their new mode. While 14.0% of the car users changed to train transport when parking tax policy of £5 was applied (see Figure 9). This implies that most car users having weighed their needs and benefits of using cars under the new tax policy regime of £2.5 still prefer making trips with cars to using train transport. However, changing the tax policy to £5 for the same set of trip maker gave a considerable decrease in the number of car users by 14.0%.

Furthermore, the gradual rise in the number of adopters (train users) and decrease in the numbers of deflectors (car users) over a period of time between 120-time steps and 193-time steps when the graph became stable (see Figure 9) was as a result of social interactions going on among passengers who are dissatisfied with the new policy hence, seeking better alternatives from happy neighbours. This explains the variability in cognitive processing behaviours shown in Figure 10. There was a reduction in the numbers of mode users repeating their previous behaviour and those imitating other users, which give rise to increase in the number of optimisers and the Inquirer mode users (see Figure 10).

From the case study model, it is evident that the framework is capable of giving insight into the development of appropriate interventions that can be used to influence passengers' mode shift behaviour. However, the models need to be tested against more real-world cases and for different modes of transport. Also, it is worthwhile to note that there are some scenarios where trip maker's behaviour might be practically impossible to stimulate due to location situations. For instance, a trip maker whose residence or workplace is not on the route of policymakers' preferred mode, may find it unreasonable to change the current preferred mode. The MOSH framework is not presently applicable in such exceptional cases.

5 Conclusions and Further Work

This paper introduced a novel modal shift framework called MOSH to support research on how to best stimulate individual trip maker's behaviour to adopt less preferred transport modes. It addressed somegaps in existing works, such as limited use of necessary socio-psychological theories of human behaviour, no distinct social interaction structures among trip makers, and no reference to trip makers' context in decision making. The MOSH framework addressed these gaps by exploring agent-based modelling method to investigate individual trip maker's attributes. It achieves that by employing the Consumat approach for social interaction structures coupled with the CWA for trip maker's contextual factors in decision making.

A hypothetical case study for investigating car to train mode shift was carried out to demonstrate the applicability of the framework in the transport domain. The result showed that the model conceptualised from the framework is capable of assisting policymakers to gain insight into how to effectively stimulate trip makers' behaviour towards adopting a less preferred mode. However, limitations in exceptional cases such as where trip maker's behaviour might be practically impossible to stimulate due to location (residence or workplace) do exist at present in the framework. Such a situation and more accurate methods of measuring perception will be looked into in the future.

In the future, we intend to look further into the concept of measuring passenger's affective effects on mode choice which forms components of spatial and temporal context that determines individual attitude. In this respect, we hope to research into the application of intelligent fuzzy-decision components to achieve this objective.

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