HOW DO TRAVELLERS DECIDE: A STOCHASTIC MODELLING APPROACH TO DETERMINE DECISION FACTOR SIGNIFICANCE

Faboya T. Olusola[(a)], Peer-Olaf Siebers[(b)], Brendan Ryan[(c)], Grazziela P. Figueredo[(d)]

[(a), (b),(d)]School of Computer Science, University of Nottingham, Nottingham, United Kingdom
[(c)]Faculty of Engineering, University of Nottingham, Nottingham, United Kingdom
[(a)]itxotfa, [(b)]pszps, [(c)]epzbr [(d)]pmzgf@nottingham.ac.uk

ABSTRACT
Many factors are involved in travellers' mode choice decision processes. Such factors include individuals' physical, cognitive, and emotional abilities, which play a significant role in travellers' attitude and mode usage patterns. Understanding how important each of these factors is to individuals, as well as understanding their impact on travellers' behaviour in general, will assist policymakers to provide appropriate interventions when necessary. To gain this understanding, we propose to use a stochastic modelling, supported by a fuzzy inference system. In this paper, we describe our approach and demonstrate it with the help of a case study, looking at cyclists and private vehicle users in the context of travelling to and from a university. The aim is to understand which of the travel requirements (physical, cognitive, and affective) is considered most when people are planning for their journey, and to understand the level of efforts regarding the three factors required to make use of their mode. The results show that both sets of travellers engage more with their cognitive aspect during journey planning, but cyclists have a higher cognitive share as a result of optimising safe routes to the university.

Keywords: stochastic modelling, fuzzy-intelligence, abstraction hierarchy, mode choice, travel requirements

1. INTRODUCTION

Researches on travel mode choice have been ongoing since the 1960s (Möller, 2014). However, the concerns on the need for transport modes shift started receiving attention in recent times. The current attention is due to persistent challenges of the sociotechnical transport system as well as substantial socioeconomic benefits that shift in the mode usage pattern can bring. Consequently, in addition to existing approaches to mitigate challenges due to the transport system, behavioural change in passengers' mode choice has been suggested as a short-term solution with reduced cost (Roberts et al., 2017). Nevertheless, the transport system organisational structures, policies and designs often impose constraints on actors' activities within the system. The constraints which could be physical, cognitive and affective (Wardman et al., 2001) are the requirements that need to be satisfied in order to make a journey and are the factors that shaped travellers behaviour in mode choice. The constraints can manifest from individuals psychological (Gardner & Abraham, 2008) and symbolic and affective (Steg et al., 2001) traits; as well as travel mode's instrumental attributes (Derek Halden Consultancy, 2003). Due to heterogeneity in human nature, the travel requirements, i.e. physical, cognitive and affective have varying impact on individuals mode choice decisions; and gaining insight into such impacts is essential to the provision of the right interventions to stimulate travellers' behaviour (Faboya et al., 2017).

Furthermore, our review of the literature indicates that factors that determine travellers' mode choice are not linear and with no apparent boundaries. Besides, individual traveller makes a subjective judgment under uncertainty due to information deficiency or the fuzziness of the decision variables boundaries. There are existing studies on mode choice, but models that look at mode shift through behavioural change are scarce. We believe the first step to achieving mode shift is to understand the decision variables (Faboya et al., 2018). To the best of knowledge, however, there is no in-depth study providing the techniques to identify the significance of the decision factors and their impacts on travellers' mode choice decision, bearing in mind the uncertainties surrounding the process.

Therefore, in this paper, we introduce a fuzzy-decision technique that analyses a transport system environment with the Human Factors' Cognitive Work Analysis (CWA), and models the perception and attitude of a set of travellers using Stochastic modelling approach. We demonstrate the application of this technique by looking at a case study, where we focus on cyclists and private vehicle users in the context of travelling to and from a university. The case study aims to investigate:

1) which of the travel requirements namely physical, cognitive or affective is paramount to travellers' mode choice decision.
2) the physical, cognitive and affective efforts demanded from the travellers to make use of their usual travel mode as a result of constraints imposed by the transport system's environment.

The outcome will provide a detailed understanding and insights into the aspects of the transport system's object, resources or process that need improvement. In addition, it will assist to identify (i) elements within the system's environment that need interventions; and (ii) the factors (ergonomics and non-ergonomics) that may require attention in order to achieve a shift in mode usage pattern.

The remainder of the paper is organised as follows: Section 2 discusses the background information, including decision factors in mode choice and their relationships, modelling uncertainty in decision-making, Human Factors' cognitive work analysis, and Monte Carlo methods. Section 3 presents data collection and analysis. Model development, verification and validation are given in Section 4. While experimentation and results are presented in Section 5. Finally, Section 6 and 7 present the results discussion and conclusions, respectively.

2. BACKGROUND

2.1. Travel Demands Consideration

Behaviour change in passengers' mode choice has been suggested to be a possible way to mitigate environmental, social, economic, and health challenges due to the transport system (Roberts et al., 2017). Nevertheless, the challenges lie in the many interdependent factors that determine traveller decision in the travel mode choice process. The considerations include the traveller's attributes such as personality, privacy etc., (Steg et al., 2001; Gardner & Abraham, 2008; Steg, 2007), social interactions; motives for mode usage and behavioural controls which include individual mental and physical ability (Wardman et al., 2001). Other considerations are the travel mode characteristics (Derek Halden Consultancy, 2003); and the system's environment (Rasmussen, 1986; Wickens et al., 2004). Mann and Abraham (2006) state that certain considerations are paramount to individual travellers in making mode choice. These considerations influence the motives for mode usage (Steg, 2005). To an individual, the motive might be instrumental such as travel time concerns (e.g. get to work on time), while others may consider symbolic-affective factors such as autonomy, personal status etc. However, Steg (2005) and Mann and Abraham (2006) observe that the majority of the existing models of mode choice have been based on cognitive antecedents of behaviour, but treat "affect" as an undifferentiated aspect of attitude formation. The researchers' assertions are due to the overlap and the fuzziness in the boundaries and interrelated nature of the mode choice decision factors. Consequently, our findings from the literature about the considerations for mode choice decisions are represented in a Venn relationship diagram in Figure 1. Our diagram explains the relationship between the mode choice decision (the centre) and its various influencing factors. The considerations in the diagram include the travel mode attributes (e.g. speed, cost); passenger attributes (e.g. status); the motives for mode use (e.g. get to work on time); and the possible behavioural influence on the mode choice decision (physical fitness). The *mode choice decision* at the centre of the relationship diagram is influenced by trip-makers' motives for using a mode which can be instrumental, symbolic-affective, or both. The decision often manifest along the considerations that the decision maker thought of being paramount.

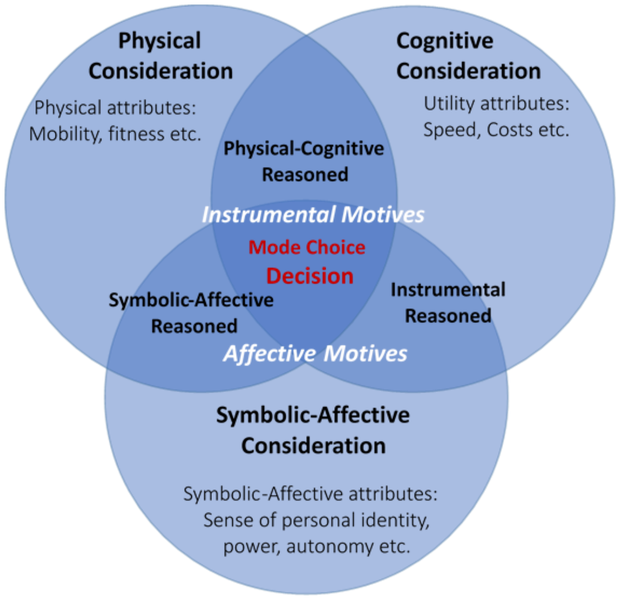

Figure 1: Travel Demands Relationship Diagram

The *cognitive consideration* is primarily driven by the utility and functional attributes of the travel mode such as travel time and speed. It also has influences from other considerations such as physical (e.g. personal mobility) and symbolic-affective (e.g. autonomy). The cognitive consideration often results in instrumental-reasoned and motives (e.g. get to work on time) (Steg, 2005). The *symbolic-affective consideration* is more psychologically related. It includes travellers' attributes such as status, superiority, personal identity etc. Mann & Abraham (2006) argue that psychological analysis of affective functions always reveals affective motives of mode use among which are autonomy, the feeling of control, etc. In addition, context (e.g. worries not to be late to an appointment) and environmental conditions (e.g. bad weather) are other forms of affective sources that influence decision-making. Lastly, *Physical consideration* is related to personal mobility, fitness, environment (e.g. platform or interchange design). Each of the factors has its degree of impact on the mode choice decision. To address the overlap and boundary issues in decision factors, a computational intelligence technique Fuzzy Logic system is discussed in Section 2.2.

2.2. Imprecise Information and Fuzziness of Decision Factors

Human beings make subjective judgements under uncertainty in decision-making processes. Two categories of uncertainty are bound to arise from the conceptual relationship diagram presented in Figure 1:

1. Uncertainty due to imprecise boundaries of the factors considered in the decision process.
2. Uncertainty due to fragmentary or vagueness of natural language as a result of imprecision of the words used in the measuring instrument, as words mean different things to different people.

When there is the possibility of uncertainty in perceptions, Zadeh (1996) suggests the Computing with

Words (CW) methodology. 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. Fuzzy logic (FL) plays a pivotal role in CW and vice versa (Zadeh, 1996). The FL idea is similar to the human being's feeling and inference process of providing vague answers to responses. For instance, to answer questions such as how satisfied are you with your travel mode today, one could answer with 'Quite Satisfied'. Quite satisfied is both fuzzy and ambiguous because it fails to indicate exactly to what degree is the satisfaction. Computers as discrete number based machines can only be used on vague responses with the help of computational intelligence techniques such as FL and fuzzy inference systems. The implementation of FL techniques to a real application involves three major steps (Bai & Wang, 2006) as depicted in the fuzzy inference system (FIS) schema in Figure 2 below:

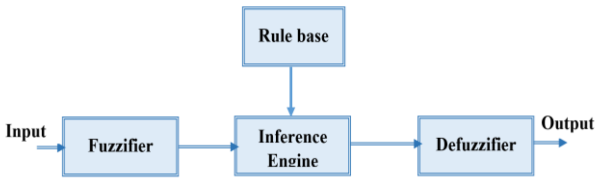

Figure 2: Fuzzy Inference System Block Diagram

- Fuzzification: the process of converting the classical or crips data into fuzzy data or membership functions.
- The fuzzy inference process: combines membership functions with the control rules to derive a fuzzy output
- Defuzzification: the use of different methods such as centrifugation to calculate each associated output and put them into a lookup table. The final output is picked up from the lookup table based on the current input during application.

The fourth box (the rule base) contains the linguistic rules that can be derived from survey data or provided by experts, and which form the bases upon which the inference engine maps the input fuzzy sets into the output fuzzy sets.

Furthermore, in addition to being able to represent uncertainty in the system, travellers' emotions is a key component of the mode choice decision-making process. The following section discusses the approach to measuring emotional perception in this study.

2.3. Measuring Traveller's Affective Response

Some of the mode choice decision factors can be obtained using common survey method such as questionnaire only, but the requirements for capturing emotional perception require additional techniques beyond such data gathering tools. A literature review in the field of Psychology unearthed that the most common method for measuring human emotion in Psychology is the "circumplex model of affect" (Russell, 1980). It is a well-established framework, which proposes that all affective states arise from cognitive interpretation 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). The two independent systems give rise to about 48 different levels of emotion, which are represented in a circular fashion of a two-dimensional space of the model. Although some emotions are similar, they are measurably different from each other. The circumplex model has been successfully implemented in areas like social behaviour (Carney & Colvin, 2010); medicine (Posner et al., 2005; Tseng et al., 2014) and e-commerce (Jascanu et al., 2010). The framework could be of great help in measuring travellers' emotional perception; however, the dynamics in travellers' activities during the journey may pose questions regarding its adequacy. Capturing traveller's perception at various stages of a journey with respect to objects and resources within the transport system's environment as the journey progresses could be complicated. Human Factors' CWA (Rasmussen et al., 1994; Vicente, 1999) discussed in Section 2.4 provides a useful investigative approach.

2.4. Overview of Cognitive Work Analysis

The CWA is a five-phase analytical framework for the evaluation of complex sociotechnical systems (Jenkins et al., 2009). Each phase of CWA models a different constraint set within the system. The overview of the five phases is detailed in Cornelissen et al. (2013), but our focus is on the first two phases. First is the Work Domain Analysis (WDA) that models the system constraints by describing what the system is trying to achieve, and how it tries to achieve it. The WDA uses the Abstraction Hierarchy (AH) to simultaneously describe constraints on the performance of actors enacted by system's characteristics (Cornelissen et al. 2013), as well as the environment in which the activity is performed. The AH represents the means-ends relationships with the system environment (Baker et al., 2008). Elements at one level of abstraction are the means to achieving elements at the next higher level, and the ends achieved by elements below. The links are made following a 'how-what-why' triad (Rasmussen & Pejtersen, 1990). It follows the 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).
Starting from the top level of the AH, *the functional purpose* of the existence of the entire transport system to

the University in the case of this study is to ensure efficient, comfortable and safe trip. The second level from the top has the *values and priority measures* nodes which are the criteria used to judge whether the system is achieving its purpose. The middle-level of the AH is the *purpose-related functions* which identify how the travel modes actually achieve the aim of providing efficient, comfortable and safe transport to the university. The *object-related processes* are processes that make use of transport system's objects to achieve the desired result. The physical objects and resources that are needed by travellers to make a pleasant journey. The second phase is the Control Task Analysis that produces a Contextual Activity Template for each purpose-related function in the AH by modelling the situational constraints and decision-making requirements. Details of an illustrative example of the AH application is given in Section 3.3.

2.5. Monte Carlo Approach

The complexity of social systems in which travellers operate (Wickens *et al.*, 2004), and their multivariate, as well as interrelated attributes, explains nonlinearity in their decision-making processes. Understanding the impact of variables that present certain levels of uncertainty, ambiguity and variability in decision process required mathematical models such as Stochastic process (Lewerenz, 2002). Stochastic modelling allows access to a range of possible outcomes of decisions and the probability that they will occur for any choice of action (Field Jr., 2008). The features make the stochastic process an ideal method to analyse the impact of variables and allow better decision making under uncertainty.

3. DATA COLLECTION AND ANALYSIS

This section presents the data collection and survey data analysis processes undertaken in this study.

3.1. Questionnaire Design

A questionnaire tagged "Passenger's Mode Shift Survey" was developed from the discussions emanated from two focus group meetings. The focus group involved a private car user, a cyclist, two pedestrians and three public transport users. The participants' views on various factors they put into consideration while planning a trip to the university were discussed. The discussions in the first meeting formed the contents of the draft questionnaire. The contents and the nature of the questions were reviewed in the second meeting. To ensure that the questionnaires measure what is expected, experts were consulted for a further review of the questions. The final version of the questionnaire was provided in online and paper-based versions to enable wide circulation.

There are two sections in the questionnaire, one focusing on demographics and one focusing on travel mode perception. The travel mode perception section consists of several Likert scale and open-ended questions. Items in the questionnaire are on the following transport system specific areas: *information provision, mode timeliness, reliability, frequency, speed, security, safety, autonomy and privacy, control over journey and protection from bad weather*. The questions are on the following focus items: ease of accessing information, reliability of available information, ease of getting to destination on time, ease of getting on and off the mode, parking space concern, delays, security en-route the university, safety en-route the university, availability of road signs, attitude of other road users and protection from weather. All the questions were intuitively asked and tailored towards mode-related scenarios so that neutrality in affect and utility measures would emerge (Steg, 2005). Each Likert scale question requires two responses, one answers *"how satisfied*", and the other answers *"how important"* is the item under consideration to the respondent.

3.2. Questionnaire Execution

The participants were:

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

The choice of the two travel modes was due to our interest in investigating the levels of efforts (physical, cognitive and affective) demanded by the transport system on the travellers, and the view to knowing which of the factors is paramount to their decisions to choose a mode.

3.3. Abstraction Hierarchy Development

Our focus items (i.e. the transport system's attributes mentioned in the questionnaire and listed in Section 3.1), together with related physical objects and resources within the university's transport system are used to construct the AH in Figure 2. Each of the *functional purposes* and *values and priority measures* nodes is shaded with unscaled two or three different colours. The colours are used to represent that each box has its potion of affective, cognitive and/or physical involvement that contributed to mode choice decision.

To illustrate how AH was constructed using the *'how-what-why'* triads. Trace through and focus on the highlighted nodes and means-ends links. For instance, if *Convenience* node is taken as the '*what*' at the *values and priority measures level,* the means-end links connecting this node up to the higher levels of abstraction show that it can support the *comfortable, functional purpose* of the system. That is, it can be seen that C*onvenience (what)* occurs to ensure that *Comfortable (i.e. the 'why')* is provided in the system. To show how the *convenience* node ('*what*') has been derived. The boxes below the *convenience* indicate that it is supported by the *travel mode protection, passenger protection, cater for biological needs desires, cater for task needs and mode real time (i.e. the 'how')*. The same process was used to form the links on the AH from the participant responses in the survey data.

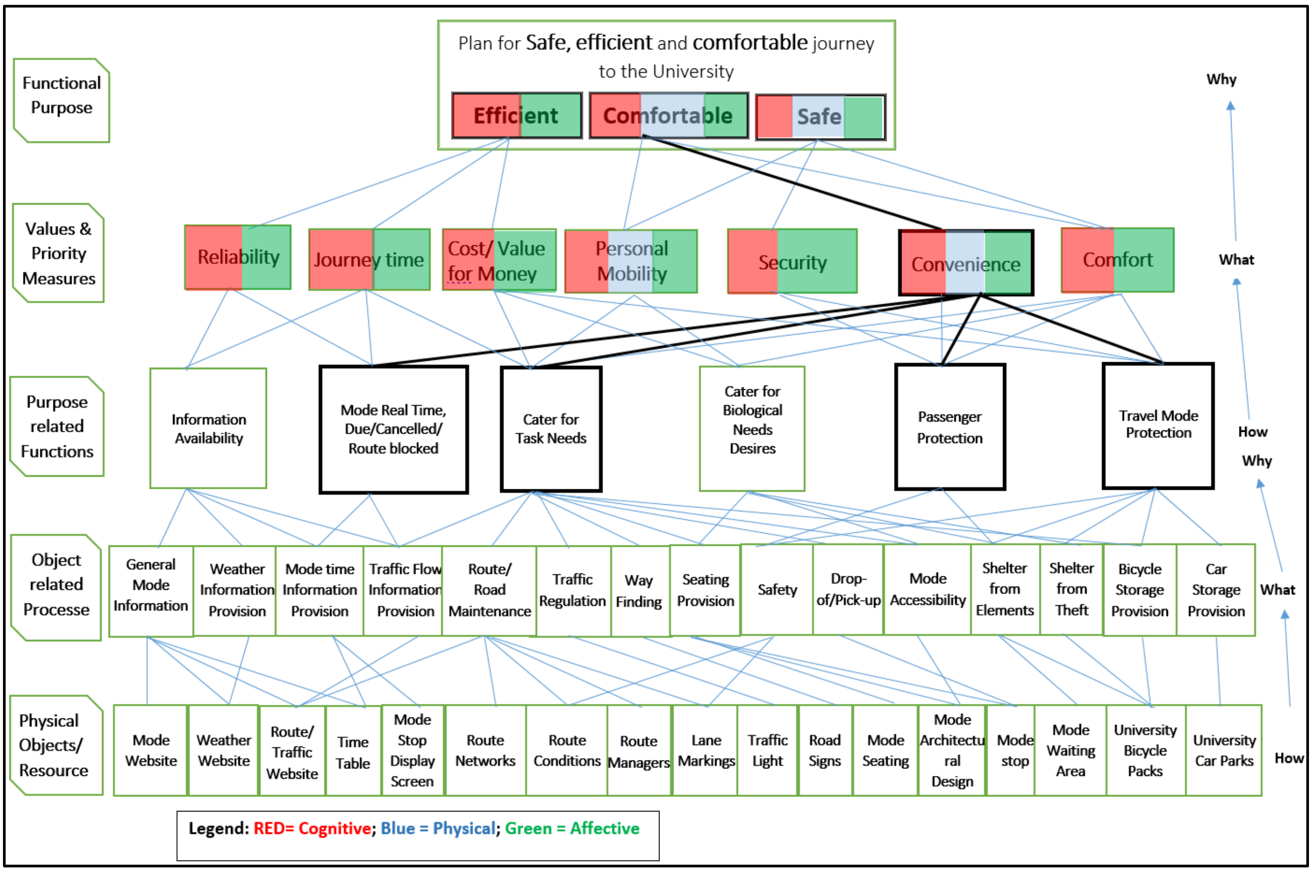

Figure 3: The Abstraction Hierarchy

3.4. Data Analysis

3.4.1. Deriving Affective Value from the Survey Data

The affective perception for each participant is derived from the survey data as follows. A two-column table is formed for the analysis. The first column contains the perception of the *importance* of the item to the decision maker, and the second has the perception of the *satisfaction*. However, in situations where more than one item is related to one travel mode attribute, the mean of responses to all questions that related to the attribute is calculated for each participant (see Algorithm 1).

The data distributions for the importance and satisfaction entries follow a normal distribution bell shape. Thus, the Gaussian membership function was used for the affective generator fuzzy system.

Algorithm 1 Affective component from survey data

Create a two-column table for *importance* and *satisfaction* attributes

1: **for** each participant **do**

2: **for** each x **do** where ⊳ x is the *focus items.*

3: Find the mean $\bar{\imath}$ and $\bar{\jmath}$ ∀ questions related to x.

where ⊳ i = importance, j = satisfaction

4: $x_i = \bar{\imath}$ and $x_j = \bar{\jmath}$

5: **end for**

6: **for** each x **do** where ⊳ x is the *focus items*

8: Generate affective values from x_i and x_j

9: Return affective value

10: **end for**

11: **end for**

The two entries (i.e. importance and satisfaction) form the two dimensions of the input into the affective fuzzy inference system. The rule base for the system follows the fuzzy mapping rule provided in Table 2.

Table 1: 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

Table 2 describes the relationship between the two inputs (i.e. arousal (importance) and pleasantness (satisfaction), and the output (affective). The interception of a row and a column represents an emotional point (affective perception). Furthermore, each participant's perceptions and his or her corresponding affective value for all mode's attributes are recorded. A correlation analysis is performed on the travellers perception values and the corresponding affective values to identify highly correlated attributes so as to reduce to a manageable size the number of attributes to be considered in the determination of the users' stereotypes.

3.4.2. Deriving Physical and Cognitive Values from the Survey Data

The travellers' physical and the cognitive aspect of the general perceptions are derived from the survey data as follows: each of the focus items is examined to determine whether it answers the question that relates to physical (mobility), cognitive (mental) or both activities. For instance, the question "*How satisfied are you with the ease of accessing information about your main mode?*", is more related to satisfaction regarding the cognitive effort to access information than the physical effort. Following this process, all focus items related to a mode attributes are classified accordingly as physical or cognitive perception. Where more than one focus item relates to a mode attribute, the average value is taken. With the derivation of the physical and cognitive perceptions from the survey data, all travel requirements (i.e. physical, cognitive and affective) values which form the input into the focus item's fuzzy decision system are in place.

3.4.3. Groups within the Population

K-Medoids clustering also known as Partitioning Around Medoids (PAM) algorithm (Agrawal et al., 2016) was used to learn the stereotypes present in the dataset. Four and three stereotypes were identified within cyclists and car users' populations respectively. Each stereotype has a range of minimum and maximum value for physical, cognitive, affective and perceived overall satisfaction within which they are grouped. The percentage of each stereotype within their respective population together with their minimum and maximum values are used for model calibration at implementation stage.

4. MODEL DEVELOPMENT

4.1. Model Conceptualisation

The study conceptual model depicted in Figure 4 shows the inputs into the system; the decision system, and the expected outputs from the system. The model development follows the conceptual design. The passenger perceives the quality of mode attributes and makes a subjective judgement on each of the focus items bearing in mind the physical, cognitive and affective efforts associated with the items being considered. Each focus item has values for importance and pleasantness as inputs from which the affective generator fuzzy system produces the affective value. The affective value is after that combined with the physical and cognitive perceptions values of the same focus item to form a set of input into the focus item decision system. The evaluation of each of the system's metrics (i.e. *value and priority measures* of the AH in Figure 2) is based on relevant and related focus items. The outputs from the focus item fuzzy system are general perception of the focus item and the physical, cognitive and affective considerations (strengths) that contributed to the general perception.

The following assumptions were made in the model design process:

1) the number of car user and cyclist participants considered in the simulation will provide information regarding their behaviours in response to the journey requirements
2) the travellers already have previous experiences of travelling to the university

A simplification that we made in the model design is that the travellers' usual mode choice behaviours are not influenced by their interactions with other traveller's behaviour.

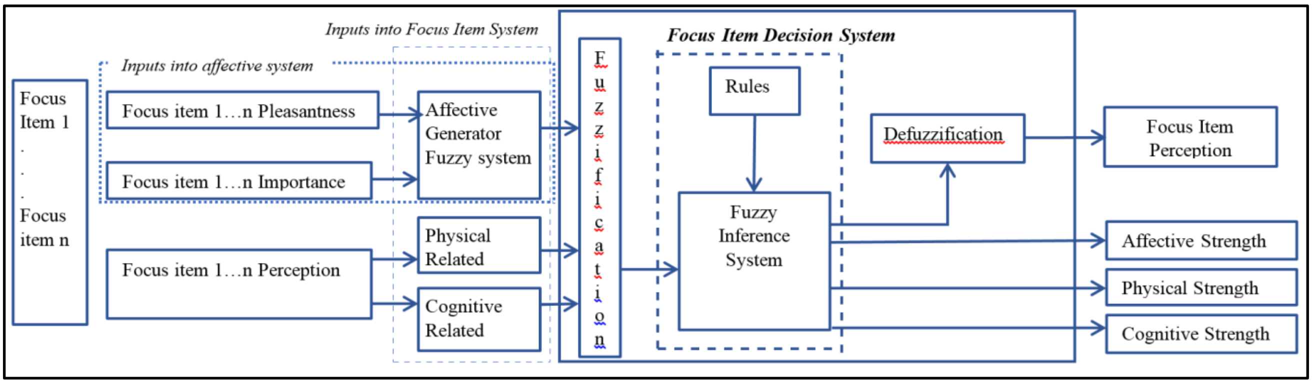

Figure 4:The Study Conceptual Model

4.2. Mode Implementation

The model was implemented in REPAST, a Java-based simulation toolkit for ABM (https://repast.github.io). There are two classes of active objects in the model: The Passenger and Mode agents. The Passenger agents are the cyclist and the car users; the Mode agents are the cycle and the personal vehicle. The model calibration was based on the stereotypes information. A population of 163 passengers consisting of 81 car users and 82 cyclists was created; the uncertainty tolerance and aspiration level parameters were randomly generated.

A fuzzy implementation of the perception process was also on a Java-based fuzzy logic toolkit called Juzzy (Wagner, 2013). The toolkit Type-1 fuzzy inference system was extended to fit the needs of this study. A section of the extension is listed in Algorithm 2. The Algorithm was executed on each of the focus items having the physical, cognitive and affective variables as input. A triangle membership function was used because of its flexibility and suitability to model distributions derived from natural phenomena, also its ability to automatically adjust its centre point to capture uncertainty/variation in the survey data. The system's rule-base consist of 27 rules derived from the relationships that exist among the survey data sets of the three input variables and the perceived overall satisfaction. The outputs from the system are: (i) the name of the input variable that contributes to the final travellers' perception. (ii) the linguistic labels (*Pleasant, Unpleasant etc.*) in the membership functions which correspond to the inputs and their respective firing strengths (i.e. the strength that the linguistic label contributed to the final perception) and (iii) the travellers' actual perception of the focus item being considered (i.e. the defuzzified value).

Algorithm 2 Identifying travel requirements that contribute to perception and their strengths

There are 3 inputs: physical, cognitive and affective each with 3 linguistic labels: Pleasant, Unpleasant and NeitherPleasantNorUnpleasant into the fuzzy system

1: Declare a Vector v to return multiple values
2: set the input i ⊳ $i_1 =$ physical, $i_2 =$ cognitive, $i_3 =$ affective
3: get rule r.size ⊳ r size is the total number of rules in the fuzzy system rule base
4: **for** each r **do**
5: **for** each x **do** ⊳ x = the linguistic labels
6: get the variable x . name ⊳ = name
7: get the variable x . Input ⊳ = crisp input
8: get the variable x. Firing Strength ⊳ = strength
9: **if** (strength >=0)
10: Map.put (name, strength)
11: **end for**
12: **end for**
13: $v.add(Map)$
14: $v.add(Perception)$
15: end.

4.3. Mode Verification and Validation

The credibility and validity of this simulation model was ensured using various techniques. Firstly, we verify that the model's algorithms was properly implemented without errors, and oversight. In addition, experts from simulation and transport research domains checked the model implementation process. Secondly, as part of the validation process, a highly correlated result of the generated affective and the corresponding travelers' perception values was obtained from the survey data. The results points to the accuracy of the expert knowledge (i.e. Circumplex model) used in the "Affective fuzzy inference system. Furthermore, the assumptions made and input parameters reflect the reality from the survey data.

5. EXPERIMENTATION

5.1. Experimental Setup

The experimentation looked into the following purposes:

1) the significance of the three travel requirements to the travellers' perception of their travel mode to the university, by observing the numbers of times physical, cognitive or affective considerations occurred in their travel experiences.
2) The level of effort demanded regarding the most considered travel requirement.

The model was executed 100 times for the population of 163 passengers consisting of 81 car users and 82 cyclists. The number of times that a travel requirement contributed to travellers' perception on each of the focus items was generated as model output. In addition, the values of individuals perceived overall mode satisfaction, perceived mode's comfortability, efficiency, and safety was also returned as outputs. The results are presented in Section 5.2

5.2. Results

5.2.1. The Significance of Travel Requirements

The significance of the three travel requirements to the travellers' modes' perception in their journey planning processes is presented in Figure 5. The vertical axis of each histogram represents the average number of times a requirement is considered; the horizontal axis shows mode counts. The diagrams on the left side of Figure 5 represent the histograms of overall travellers' *physical*, *cognitive* and *affective* considerations, respectively. Each histogram represents the average number of times that a travel requirement occurs in a traveller's planning process for 100 simulation runs. The top left diagram shows the overall average physical considerations for car users as 307.32 and 140.00 for the cyclists, respectively. The middle left diagram indicates that the average cognitive consideration has the highest number of occurrences for both modes with an average of 1101.09 for car users and 1181.00 occurrences for cyclists. The bottom left diagram presents the average affective considerations with car users having an average of 125.22 and cyclists having an average of 184.00 occurrences. The output shows that both sets of users involved more in mental thinking in their planning than physical and affective considerations.

However, due to high values recorded in cognitive consideration, further investigation into the breakdown of its linguistics labels' (i.e. pleasant, unpleasant, etc.) distributions counts is depicted in the diagrams on the right side of Figures 5. The "pleasant cognitive considerations" histogram (top right diagram) indicates that the car users achieved average of 602.27 occurrences of pleasant cognition (i.e. satisfactory) while cyclists have an average of 552.00 pleasant cognition occurrences. The right middle diagram shows the "neither pleasant nor unpleasant considerations" histogram, an average of 375.54 occurrences of neutrality is recorded with the car users' and an average of 384.00 for cyclists, respectively. The bottom right diagram shows an average of 73.22 occurrences of "unpleasant cognitive considerations" for car users, and 202.00 occurrences occur for cyclists

.

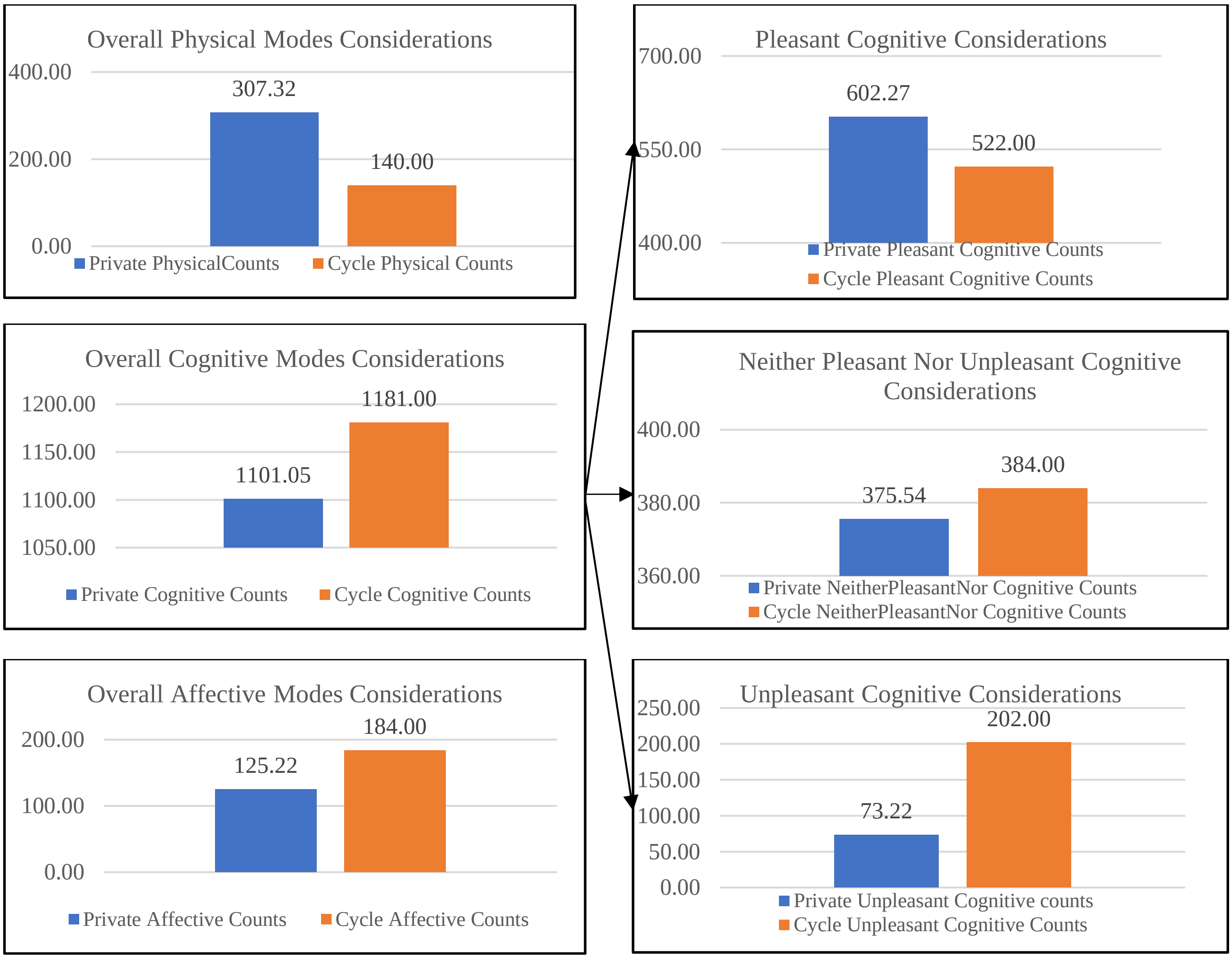

Figure 5: Overall Physical, Cognitive and Affective Travel Requirements Considerations

5.2.2. Effort Demanded by the Travel Requirements

This result focus on the perceived efforts regarding cognition put into the use of the modes. The cognitive demand is investigated further because of the number of occurrences in both modes' perception. The representations of each of the cognitive requirements are observed within the modes *functional purposes* (i.e. mode *efficiency*, *comfortability* and *safety*) that form the travellers' perceived satisfaction.

Jaccard's distance measures that gives statistical dissimilarity between two sets was used to determine dissimilarity between the travellers' perceived satisfaction and cognitive involvement in each of the modes' functional purpose. It indicates that the closer the distance to zero the lower the level of dissimilarity. Figure 6 shows the cyclist perceived satisfaction level (blue points) and the *safe*, *efficient* and *comfortable* purpose cognitive demand. The satisfaction-safety set has 0.0714 distance of dissimilarity; satisfaction-comfortability set has a negative value of -3.4629, and satisfaction-efficiency set has another negative value of -7.0894. The values show that cyclists perceived cognitive efforts on safety have a close relationship to their perceived satisfaction, but the cognitive efforts put into comfort and efficiency are at variance to the perceived satisfaction, which indicates that they are not

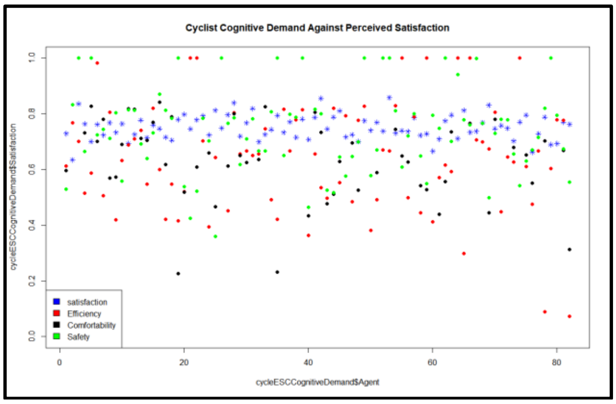

Figure 6: Cyclist Perceived Satisfaction and Cognitive Demand Relationships

important determinants of cyclists' satisfaction. Furthermore, the negative values can be attributed to the travellers' perceptions on the metrics from which efficiency and comfortability were developed and also the focus items that form the metrics (see AH Figure 2). For instance, mode *reliability, journey time and cost/value for money* are the metrics that form the *efficiency (functional purpose)*. Thus, it shows that cyclists do not put much emphasis on journey time, cost

and value for money as much as they put to the safety while planning for their journey to the university.
Figure 7 shows the car users perceived satisfaction level (blue points) and the *safe*, *efficient* and *comfortable* purpose cognitive demand. The Jaccard's distance measures indicate the satisfaction-safety set has 0.4548 dissimilarity distance, the satisfaction-comfortability set has dissimilarity of 0.2773, and satisfaction-efficiency set has 0.5888 of dissimilarity. The values show that car users' perceived cognitive efforts on comfortability is least dissimilar to satisfaction compared to safety and efficiency.

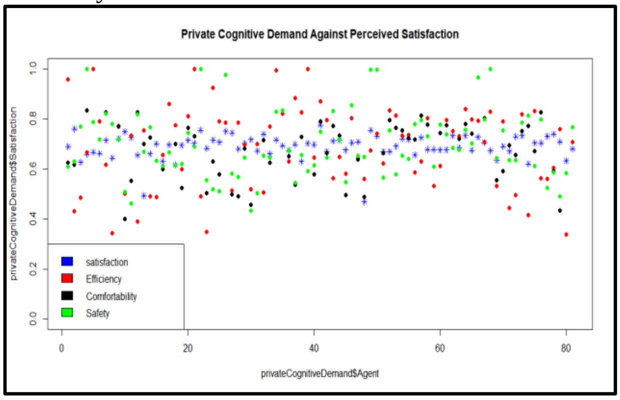

Figure 7: Car users' Perceived Satisfaction and Cognitive Demand Relationships

Although all the Jaccard distance values are positive, the high dissimilarity in efficiency can be attributed to reliability, journey time and costs. From the questionnaire transcripts, most car users expressed displeasure about the high cost of parking fee within the university. Also, some mentioned peak hour delays as part of the reasons to plan around time to set out or the routes with less traffic; these are the factors that determine the mode efficiency according to the AH in Figure 2. However, the low dissimilarity value in satisfaction-comfortability set reflects the common knowledge that personal vehicles have better comfortability experience than other modes in terms of protection against bad weather, ease of visiting secondary places etc.

6. DISCUSSION

It was observed in the experiment that cognitive considerations in planning for a journey to the university have the highest number of occurrences for both cyclists and car users. The survey provides the reasons for high cognitive considerations. The survey transcripts recorded that factors such as concern over journey time to avoid traffic delays, as well as parking space when arrived the university at a particular period contributed to car users' high cognitive considerations. The cyclists, on the other hand, are more concerned about their safety, therefore, plans for safe and direct routes with fewer obstructions or with less mounting/dismounting during the journey. Moreover, the top right and right middle diagram in Figure 5 indicate that both modes have fairly the same number of occurrences of pleasant and neutral cognitive experiences, but the bottom right diagram in Figure 5 shows that cyclists have more number of occurrences of unpleasant cognitive experiences compared to the car users. The experience can be attributed to factors such as the attitude of other road users, which always contribute to their planning to use less busy and direct cycle routes to the university. More importantly, the need for planning around available information regarding the journey (e.g. road closed due to construction) and daily weather condition is an essential part of cyclists' daily experience.
Regarding the level of effort demanded by the travel requirements, Figure 6 shows that cyclists level of exerted cognition to achieve safety almost correspond to the perceived satisfaction when compared to cycling efficiency and comfortability. This can be attributed to some factors (e.g. attitude of road users, and bad weather etc.) as earlier mentioned. The car users comfortability reflects the general perception about the car comfort. However, the insight from the results points to the fact that policymakers need to encourage more pleasant travel experience for the university-bound cyclists, by focussing on improving items that contribute to safety, such as general route network management, and lane markings (see Figure 2). In addition, attitudes such as obstructing the cycle route should be discouraged, and public awareness of the need to respect the right of cyclists is essential. With the measures in place, car users to the university may be encouraged to shift mode to cycle. Moreover, for car users, as the university does not have a responsibility to improve traffic flow, more parking space around the offices at a reduced price will likely improve their experience.
The results of the experiments show that the technique is capable of providing insight into the level of consideration placed upon each of the travel requirements. They also show how these considerations impact on travellers' overall mode perceptions. The information provided will help to identify the area of concern of individual travellers and assist in providing necessary interventions. However, this is just a means to an end in order to further develop our Modal Shift (MOSH) framework (Faboya et al., 2017), where we look into how travellers' interactions with other travellers and their environment influence their mode choice decisions. The MOSH framework employs a more complex agent-based modelling approach. It will allow studying the impact of interventions on travellers' behaviour.

7. CONCLUSIONS

Travellers' mode usage is guided by many factors, among which are travel requirements namely physical, cognitive and affective consideration. Detail insight into the importance and the impact of each requirement on individuals' mode usage experience is essential for the provision of interventions for the enjoyable daily journey and stimulation of travellers' mode choice behaviour. In this paper, we have used a Monte Carlo stochastic approach with fuzzy-decision techniques to model travel mode perception of a set of cyclists and private cars users to a university. The survey focused on the constraints imposed on the travellers by the available objects and resources within the transport system. The data collected were analysed with the Human Factors' abstraction hierarchy to determine the relationships among the transport system's objects, the constraints that the objects imposed on the travellers. The results of the model revealed that both sets of users engaged in more cognitive consideration than physical and affective, and the reasons for their considerations were explained

It is believed that the method presented in this paper will be helpful in providing insight into the level of considerations given to travel requirements by travellers, and how the requirements for travels influences travellers' overall mode perceptions. The study will also help transport managers by providing reliable indicators to aspects of travellers' experience that needs improvement. However, limitations are found in the use of Likert scale questionnaire for data collection, because some participant responses might not be adequately captured. In the future, we intend to make a further test of the affective generator's expert knowledge (i.e. circumplex model) with relevant statistical tool against more real-life data to establish its reliability. In addition, we intend to investigate travellers' social interaction and emergent behaviour. We believe agent-based modelling and simulation will enable us to understand further how the travellers respond to behavioural stimulation when exposed to different interventions.

References

Agrawal, U., Soria, D., Wanger, C. (2016): Cancer subtype identification pipeline: A classifussion approach. In IEEE *Congress on Evolutionary Computation*.

Bai, Y., & Wang, D. (2006). *Fundamentals of Fuzzy Logic Control – Fuzzy Sets, Fuzzy Rules and Defuzzifications*. *Adv Fuzzy Logic Tech in Industrial Applications*. Berlin: Springer.

Baker, C., Naikar, N., & Neerincx, M. (2008). Engineering planetary exploration systems: integrating novel technologies and the human element using work domain analysis. *International Astronautical Congress*.

Carney, D. R., & Colvin, C. R. (2010). The Circumplex Structure of Affective Social Behavior. *Social Psychological and Personality Science*, *1*(1), 73–80.

Cornelissen, M., Salmon, P. M., McClure, R., & Stanton, N. (2013). Using cognitive work analysis and the strategies analysis diagram to understand variability in road user behaviour at intersections. *Ergs*, *56*, 764–80.

Derek Halden Consultancy. (2003). *Barrier to Modal Shift*. Retrieved rom http://www.gov.scot/Resource/Doc/47176/0026887.pdf

Ekkekakis, P., & Petruzzello, S. J. (2002). Analysis of the affect measurement conundrum in exercise psychology: IV. A conceptual case for the affect circumplex. *Psychology of Sport and Exercise*, *3*, 35–63.

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

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

Field Jr., R. V. (2008). *Stochastic Models: Theory And Simulation*. *Sandia, Report SAND2008-1365*.

Gardner, B., & Abraham, C. (2008). Psychological correlates of car use: A meta-analysis. *Transportation Research Part F*, *11*, 300–311.

Jascanu, N., Jascanu, V., & Bumbaru, S. (2010). Toward Emotional E-Commerce. *Agent and Multi-agent Technology for Internet and Enterprise Systems* (Studies in, Vol. 289, p. 345). Berlin Heidelberg: Springer.

Jenkins, Daniel P, et al (2009). *Cognitive Work Analysis: Coping with Complexity*. Abingdon, GB:

Lewerenz, M. (2002). Monte Carlo methods: Overview and basics. *NIC Series*, *10*, 1–24.

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

Möller, D. P. F. (2014). *Introduction to Transportation Analysis, Modeling and Simulation*.

Posner, J., Russel, J. A., & Peterson, B. S. (2005). The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology. *Dev and Psychopathol*,*17*(03).

Rasmussen, J. (1986). *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering.* Elsevier Science Ltd.

Rasmussen, J., & Pejtersen, A. M. (1990). *Taxonomy for Cognitive Work Analysis*. *Analysis* (Vol. 157).

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

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

Russell, J. A. (1980). A Circumplex Model of Affect. *J of Personality and Social Pscychology*, *39*(6), 1161–1178.

Steg, L. (2005). Car use:Lust and must. Instrumental, symbolic and affective motives for car use. *Transp Res Part A: Policy and Practice*, *39*, 147–162.

Steg, L. (2007). Sustainable Transportation. *IATSS Research*, *31*(2), 58–66.

Steg, L., et al. (2001). Instrumental-reasoned and symbolic-affective motives for using a motor car. *Transp Res Part F: Traf Psy and Behaviour*, *4*(3), 151–169.

Tseng, A., et al. (2014). Using the circumplex model of affect to study valence and arousal ratings of emotional faces by children and adults with autism spectrum disorders. *J of Aut and Dev Disorders*, *44*(6), 1332–1346.

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

Wagner, C. (2013). A Java based Toolkit for Type-2 Fuzzy Logic. In *Proc IEEE Symp on Comp Int*.

Wardman, M., Hine, J., & Stradling, S. (2001).

Interchange and Travel Choice Volume 1.
Wickens, D. C. et al. (2004). *An Introduction to Human Factors Engineering* (2nd ed.).
Zadeh, L. A. (1996). Fuzzy Logic = Computing with Words. *IEEE Trans ON Fuzzy Systems*, *4*(2).