Would you cross the road? Modelling interactions between the factors influencing pedestrians' decisions when exposed to automated vehicles

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Would you cross the road? Modelling interactions between the factors influencing pedestrians’ decisions when exposed to automated vehicles

Introduction: The advancement of Autonomous vehicles (AVs) is an ongoing process. Novel concepts are being tested and validated frequently to improve AVs’ functionality. An expected benefit of AVs is the improvement of vulnerable road users’ safety. While interacting with human-driven vehicles, pedestrians seek out visual cues provided by the driver such as eye contact or hand gestures to make decisions. These communication means may be absent in AVs. In these situations, pedestrians may misinterpret the AVs’ intention, thus causing confusion. Therefore, it is necessary to first analyze the factors considered by pedestrians to understand how they make decisions while interacting with an AV. More insight can be obtained from a study conducted to see the interaction between factors. **Research objective:** This research focuses on four factors, namely, urgency of the task, weather conditions, social contagion, and road markings. This research aims to determine which factors has more weight made by the pedestrian while crossing a road. **Methodology:** The analysis will be conducted based on the Anderson’s experimental protocol, supported by the information integration theory. **Outcomes:** The results from this study are expected to quantify which factors affect the decision-making process and the importance of each factor from a pedestrians’ perspective.

CCS CONCEPTS • General and reference • Document types • Surveys and overviews

Additional Keywords and Phrases: Automated vehicles, Pedestrian Road Crossing, Anderson’s Experimental Protocol, Information Integration Theory

1 INTRODUCTION

The idea of Automated Vehicles (AVs) on roads belonged merely in fiction during the mid-20th century, and only in the mid-1980s the inherent concepts for the development of AVs were established [1]. There have been many technological advancements to transform traditional vehicles into systems that can make decisions without requiring drivers' intervention. In the future, it can be expected there will be numerous daily interactions between AVs, conventional vehicles and other road users, including pedestrians [5]. The Society of Automotive Engineers (SAE) has differentiated the various degrees of automation using a taxonomy ranging from level zero through five [16]. Table 1 below shows the role of the human in the driver's seat in vehicles with different levels of automation based on the latest SAE version known as SAE J3016 [30].

Table 1: Role of the human driver based on SAE automation levels.

Level 0	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Constant vehicle supervision required			Supervision is required only in some circumstances	High (level 4) and full (level 5) automation in all conditions	

The progress of driving automation is expected to decrease the instances of accidents, traffic congestion and improve mobility in ageing societies [11]. On the one hand, AVs can perform tasks such as detecting obstructions in the road environment, route planning, navigating, speed control and parking without the need for directions from humans, thus the imminent human errors could be reduced, eventually lowering the Road Traffic Crashes (RTCs) to some extent [20]. On the other hand, a misunderstanding of AVs' intentions might potentially create untrust and uncertainty among other road users, leading to unsafe decisions [22].There might also be cases of bullying behaviours where road users may step in front of an AV to test its capability, thus causing frequent interruptions of AVs [29]. As most AVs are not yet at full scale deployment, various new applications are being developed to mitigate the negative effects of AVs on road users and improve their functionality [20]. This would be beneficial to vulnerable road users, especially pedestrians [9]. Pedestrians are known to be the most adaptable (i.e. can respond quickly) but also the most unpredictable (i.e. difficult to control with regulations) type of road users [9]. A pedestrians' perception of AVs is essential to be understood by researchers and manufacturers alike to identify the caveats of AVs concerning design features [10].

At road crossings, pedestrians undergo complex decision-making processes dependent on several factors [5]. These factors are mentally processed by the pedestrians as they assess the risk in their vicinity. To make a well-informed decision, pedestrians need to be able to perceive true levels of risks and expose themselves to an acceptable risk level [4]. Wilde's risk homeostasis theory compares risk perception to risk acceptance, i.e. the stimuli are evaluated and compared to acceptable risk levels in specific situations [27]. This means that if pedestrians feel that the use of an AV is going to lower their levels of risk below that of their personal threshold, they tend to engage more in risky behaviours such as stepping in front of an approaching AV to cross a road faster [17]. Table 2 contains some recent studies that either predict or evaluate the pedestrian's decision to cross, based on different controlled scenarios (modalities) made up by combining several factors.

Table 2: Examples of recent research studying the effect of scenarios on pedestrians' road crossing decisions.

Independent variables/ modalities	Dependent variable	Sample literature
Task urgency, legal presence, and social cues	Pedestrian road crossing decision	[23]
Vehicle speed, task urgency, and type of automation	Prediction of road crossing intention	[29]
Type of external human-machine interface, vehicle movement, and type of automation	Time taken to make a road-crossing decision	[6]

Factors that affect pedestrians' road crossing decision can be situational, environmental, or socio-demographic [24]. These factors are perceived by the pedestrian in form of real-time auditory or visual cues [21], or based on experiences from previous interactions. While crossing a road, pedestrians seek out eye contact, visual gestures (e.g. hand-raising) [9,22] and auditory stimulus such as horn sounds from the driver [13]. These cues influences their decision to cross the road. Moreover, pedestrians also consider other factors such as implicit behaviour of the vehicle e.g., appearance, speed and yielding behaviour [7].

An example of a situational factor is the urgency of a task, which was found to be influenced by the pedestrians' trip purpose [15]. Cœugnet et al. [8], and Şahin et al.[23] have concluded that the urgency of task is directly related to a road crossing decision i.e., if the pedestrian is in a rush, they tend to decide to cross a road even in risky situations. The weather condition of the crossing location is an environmental factor. Weather conditions have been known to influence the pedestrians' perception of stopping distance estimation of the incoming vehicles [25]. Thus, this factor can give an insight into how it ultimately affects a crossing decision. Social contagion is a type of socio demographic factor, which was found to vary from place to place as discussed in Pelé et al. [21]. In addition to the above discussed three factors, road markings, i.e., zebra crossing is also considered in this research. The inclusion of this factor was done in research by Zhao et al. [29], to study if pedestrians would cross a road in absence (or presence) of zebra crossings in varying scenarios of task urgency.

2 PROBLEM STATEMENT

The studies presented in Table 2 show how some factors affect the pedestrians' road crossing decision, but not how the modalities from each factor interact with one another. It is therefore of paramount importance to analyze the interactions between these factors to further our understanding with respect to pedestrians' decision-making at road crossings. In addition, informal cues such as facial expressions and eye contact may no longer be available in AVs [7], specifically in SAE level 4 or 5 AVs [20]. This is bound to cause some levels of ambiguity among pedestrians in terms of decision making when they are trying to safely cross a road.

Since AVs are still very uncommon on public roads, a certain level of hesitation or confusion may be expected from pedestrians while they are trying to cross a road when exposed to AVs [12]. Thus, researchers need to evaluate the relationship between one or more factors, as the road environment is an interactive socio-technical environment, to shed light on the most important factors affecting pedestrian's road crossing decision when interacting with an AV.

3 RESEARCH OBJECTIVE

The focus of this research is to understand the relationship between the selected factors (i.e., urgency of the task, weather conditions, social contagion, and road markings) and to find out how the modalities of these factors affect pedestrians' road crossing decision. Based on the existing literature, the hypotheses of the present paper posit that some factors may have more weight than other factors and they impact each other in a certain way. Additionally, some factors may not bear an influence on pedestrian road crossing decision. This research seeks to explore the potential associations between factors from a selected set.

4 METHODS

4.1 Selection of factors

In this study, four factors have been selected to further the understanding of pedestrian road crossing decision. The selection of factors was based on existing literature as explained in sections above. Factors that have been extensively researched in the past (e.g. social contagion), as well as factors that have not been explored in depth (e.g. weather conditions), were selected for this analysis. Each of the four factors as shown in Figure 1 will have two dimensions: urgency of task (urgent vs. not urgent), weather conditions (rainy vs. sunny), social contagion (present vs. absent) and road markings (zebra crossings present vs. absent).

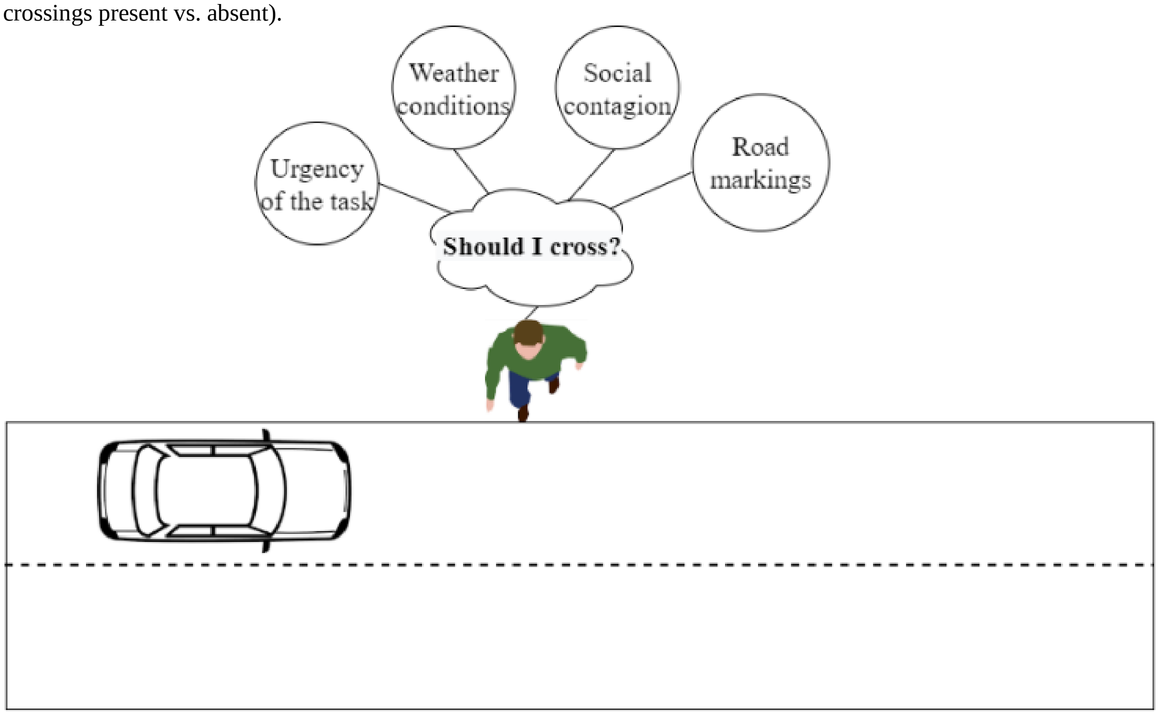

Figure 1: Factors selected for Anderson's experimental protocol.

To understand the links between different factors (for example, urgency of the task and road markings or weather condition and road markings) affecting road crossing decision when exposed to AVs, an experimental protocol developed by Anderson [3] can be implemented. Anderson's experimental protocol is a method based on information integration theory, where different variables and their mutual interactions can be simultaneously observed [3]. The method assumes that there is either an averaging, adding or multiplying mathematical function while different stimuli are being perceived in a decision-making process [2]. A benefit of using the information integration theory is that the researcher can understand how participants make decisions in their daily lives [19].

In a study by Delmas et al. [11], the relationship between road type, weather condition, traffic congestion level and vehicle speed was investigated using Anderson's experimental protocol. It allowed to determine which factors had the most influence on the perceived comfort of a driver. Similarly, Monsaingeon et al. [19] implemented the protocol to determine drivers' compliance with an automatic driving system. They manipulated variables such as weather conditions, road marking quality, road curvature and limits of automation available in the test AV.

4.2 Experimental design

Each of the selected factors are composed of two modalities that are combined with one another in a questionnaire. Within-subject experimental design will be carried out i.e., all the participants are exposed to a total of 2x2x2x2 =16 modalities. The participant will have to respond to whether they would cross the road or not when an AV was approaching them under each of the modalities. This measure of intention will be collected using a discrete 20-point scale that ranges from "definitely cross" to "definitely not cross". Monsaingeon et al. [19] did not use numbering system in the scale to avoid the possibility of numbering preference bias among the participants. Thus, in this study, the participants will have to move a slider between two opposite choices.

The participant will be put in the place of an imaginary protagonist with similar characteristics in terms of age and gender to mentally visualize the road crossing scenario. This way, the participants can project themselves into the situation and number preference bias can be avoided [19]. Monsaingeon et al. [19] allocated four different protagonists based on gender (female or male) and age (below or above 40 years old). In this research, the protagonists will be named Agatha (female, above 40), Olivia (female, below 40), David (male, above 40) and Jacob (male, below 40). A few examples of modalities combination involving an imaginary pedestrian in a road crossing situation are given below:

1. It is a sunny day. Olivia is taking a leisurely walk. A vehicle is approaching her at a fair distance and a fair speed. She wants to cross the road using a zebra crossing but other people are waiting for the vehicle to pass. If you were Olivia, would you cross the road?
2. It is raining. Olivia is in a rush. She can see other people crossing the road but there is no zebra crossing close by. A vehicle is approaching her from a fair distance and at a fair speed. If you were Olivia, would you cross the road?

The participants will also be provided with an introductory paragraph outlining the explanation of the factors and the meaning of fair distance and speed, to set a baseline scenario. The questionnaire will be online, anonymized, and non-identifiable. It will be distributed among potential participants after receiving ethical approval from concerned ethics departments.

5 EXPECTED OUTCOMES

This section includes the results that can be expected following Anderson's experimental protocol methodology. Figure 2 shows how the responses may vary among pedestrians. The responses from the participants can be used to examine the main effects of the factors through the Anderson's methodology [2]. An Analysis of Variance (ANOVA) will be conducted to analyze the results and determine whether there are significant differences between the values across the factors explored [11,19].

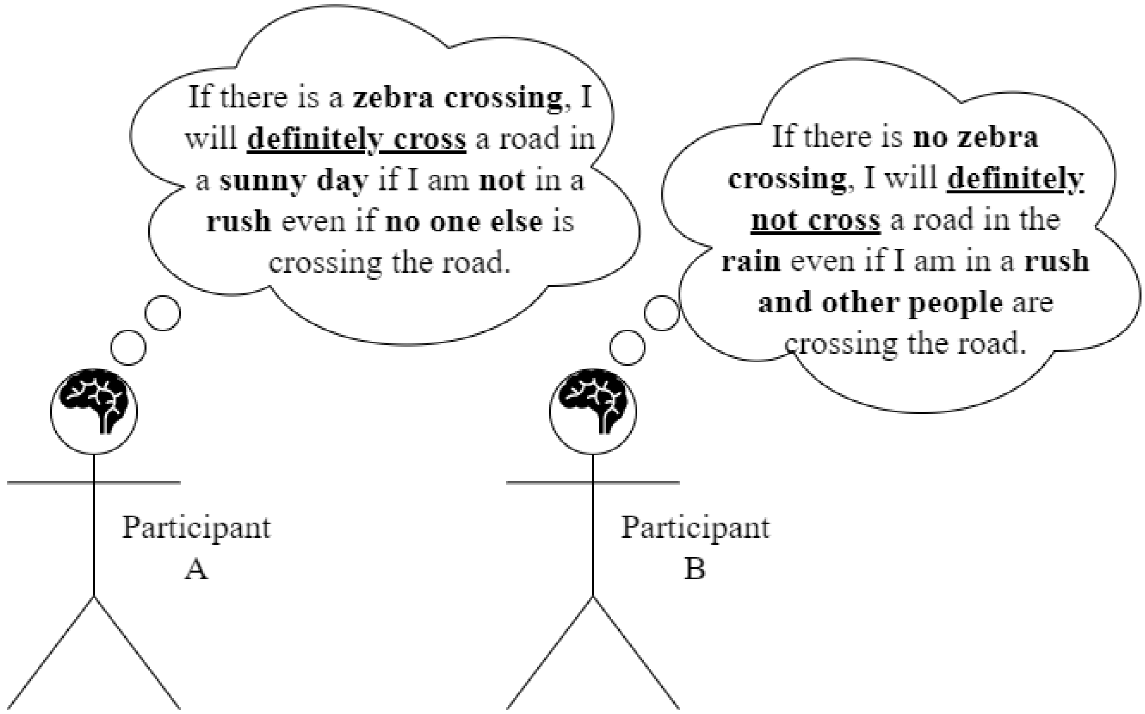

Figure 2: Expected variation in responses among participants.

Furthermore, participants' profiles can be divided into clusters using the K-Clustering means method [14]. The clusters can be tested to see if they differ in socio-demographic characteristics of the road user such as age and gender [19]. Table 3 below shows expected examples of clusters and their characteristics that can be generated from the participants' pool.

Table 3: Expected clusters of varying participants' profiles.

Cluster 1: Compliance with traffic rules	Cluster 2: Averse to social contagion	Cluster 3: Task-oriented
The presence or absence of zebra crossing has greater weight on the road crossing decision for this cluster.	The presence or absence of social contagion has the least weight on the road crossing decision for this cluster.	The urgency of the task has the greatest weight on the road crossing decision for this cluster.

6 FUTURE WORK

The results obtained from Anderson's experimental protocol and K-means clustering will be used in a Virtual Reality (VR) study where pedestrians' decisions to cross the road will be analyzed. Only the factors and clusters that were found to have the most weight would be manipulated in the VR study. This objective can form another research study which analyzes pedestrian decisions that can be analyzed based on the gap acceptance of the pedestrians [8,28] or decision-making [6] and response time. Such data provides insight into the factors that need to be taken into account by an AV so that it can make an appropriate estimation on pedestrian crossing behaviour [18,26].

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