MORAL DILEMMA FACING AUTONOMOUS VEHICLES: INSIGHTS FROM STATED PREFERENCE SURVEY IN THE CONTEXT OF SINGAPORE

Siying Zhu, Shen Loong Walt Tay, Cheng-Hsien Hsieh
School of Business, Singapore University of Social Sciences, Singapore 599494

ABSTRACT

Purpose: With the rapid development of autonomous vehicles, the transportation industry is experiencing significant changes in recent years. Level 5 autonomous vehicles possess the highest level of vehicle automation, where drivers' intervention is no longer needed. Nevertheless, the moral dilemma arises accordingly as the autonomous vehicle needs to control and regulate its own driving pattern and make the optimal decision when it is involved in any traffic accident. This preliminary study explores the perception of moral issues from potential autonomous vehicle users and how the perception affects the design of autonomous vehicles facing moral dilemmas.
Design/methodology/approach: In this study, we conduct a stated preference survey to explore the preferences of prospective users regarding different decision-making models in the context of Singapore when they are presented with moral dilemma situations involving Level 5 autonomous vehicles, where descriptive analysis and discriminant analysis are utilised to analyse the survey results.
Findings: Analytical results indicate that different levels of expectations for autonomous vehicles lead to stronger beliefs in the artificial intelligence (A.I.) algorithms handling moral dilemmas. However, gender and respondents' hazard perception do not significantly influence the attitudes of respondents towards the development of decision-making models for autonomous vehicles. The results also show that rebates in insurance premiums and legal liability were effective in engendering a change in respondents' preferences towards a moral model developed by A.I. as the autonomous vehicle decision-making model. Moreover, two groups regarding the expectation of autonomous vehicles are identified based on the discriminant analysis.
Research limitations/implications (if applicable): Level 5 autonomous vehicles are not yet reached marketability in Singapore. A stated preference survey, instead of a revealed preference survey, was thus employed, in which respondents might overstate their valuation or expectation of a particular good, service or outcome.
Originality/value: The results of this study can provide policy implications to transportation planners and manufacturers in developing the decision-making model when Level 5 autonomous vehicles face moral dilemmas.

Keywords: Level 5 autonomous vehicle, Moral dilemma situations, Stated preference survey, Discriminant analysis, Policy implications

1. Introduction

In recent years, the transportation industry has undergone significant changes due to the rapid development of autonomous vehicles (AVs). On the domestic front, the Singapore Government earmarked AV as a Smart Nation Initiative (Smart Nation, n. d.) and allocated the entirety of western Singapore, comprising 1,000 km of public roads, for AV testing and development (Abdullah, 2019). This underscores the sheer importance accorded to AV development and eventual usage in Singapore. Furthermore, the advancement of 5G technology worldwide and in Singapore, with an ambitious goal of complete island coverage by 2025 (Loh, 2020), could further fuel AV demand since 5G networks enable the usage of C-V2X technology interface by AVs in proximity with each other to communicate and synchronise speeds, enhancing AV safety (Shankland, 2019). These factors are poised to persist well into the future, precipitating the proliferation of AV usage worldwide and in Singapore, forming the impetus for addressing the moral dilemma without delay.

The definition of AVs, derived from the Society of Automotive Engineers (SAE) J3016 standard, spans six entries, levels 0 to 5, ascending in incremental autonomy progression, from completely dependent on human control to completely autonomous. The chief complexity of operating level 5 AVs stems from their complete autonomy, omitting the need for human driver intervention. This means the AV onboard system logic must make traffic decisions by itself and will face decision-making conflicts during traffic accidents if loss of life is determined to be inevitable, by weighing the lives of pedestrians versus those of passengers, making snap decisions minimise the costs from a traffic accident in terms of human lives.

The pressing issue of implementing the most optimal decision-making model for AVs is exacerbated by the increasing costs in terms of human lives. In 2018, Elaine Herzberg was the first person killed by an AV, owned by Uber, which failed to identify Herzberg as a collision danger rapidly enough (Cellan-Jones, 2020). This indicates greater urgency to upgrade the decision-making capacities of AVs to avoid similar tragedies in future.

Ultimately, the moral dilemma is about sussing out the most optimal trade-off between the lives of pedestrians and passengers in traffic accidents for a Level 5 AV. Furthermore, the optimal trade-off would serve as a behaviour guide or course of action for the AV to adopt when engaged in potentially deadly traffic situations. This moral dilemma should be addressed promptly more than ever owing to the rising proliferation of AV usage worldwide and in Singapore. Thereby, in this study, we aim to investigate the expectations of prospective AV users in Singapore when they are presented with moral dilemma situations involving Level 5 AVs based on a stated preference (SP) survey. We utilise descriptive statistics to analyse the survey results, and further discuss the related insights and policy implications regarding Level 5 AVs' decision-making models.

The remainder of this paper is organised as follows: Section 2 reviews recent research on the pros and cons of AV development, followed by its applications in Singapore. Section 3 presents the data collection and the research approaches. The results and discussions are expressed in Section 4, while Section 5 shows a conclusion.

2. Literature Review

A number of studies have addressed the AV decision-making issue and moral judgement. For example, Awad *et al.* (2018) uncovered cross-cultural ethical variations in the expected behaviour of AVs in collisions, deriving three distinct clusters of responses, and discussed how these preferences could be the basis for a global and socially accepted set of guidelines for AV decision-making. Pickering *et al.* (2019) investigated the application of an ethical Model-To-Decision (M2D) procedure for AVs to abide by during collisions and formulated a mathematical model of collision scenarios for determining collision severity in terms of overall injuries suffered. Kallioinen *et al.* (2019) explored the distinct moral beliefs pertaining to human drivers and AVs in dilemma situations, from the perspectives of AV occupants, pedestrians, and observers, based on two case studies using virtual reality and animation, respectively.

Mosquet *et al.* (2015) found that nearly 1,500 drivers surveyed in the United States expressed strong sentiments towards purchasing a partially or fully autonomous vehicle, of which 20% were willing to pay $5,000 more for enhanced in-vehicle features. The growth rate of global AV market demand is projected to be sustained at a compound annual growth rate of 63.1% between 2020 and 2027 (Grand View Research, 2020). This is indicative of changing consumer mindset in favour of AV, notwithstanding higher ownership costs.

In the context of Singapore, KPMG's (2020) Autonomous Vehicle Readiness Index 2020 evaluated the preparedness of 30 countries in supporting and implementing AVs on a nationalised scale. Their findings revealed that Singapore clinched the pole position ranking for public policy and legislation. Chng and Cheah (2020) intended to understand the general opinion on the usage of AV as public transport in Singapore, where a survey of 210 respondents has been conducted in Singapore in 2018. This study aims to further investigate respondents' preferences for different AV decision-making models in situations where they are confronted with the moral dilemma of choosing between sacrificing the AV's occupant or a pedestrian.

However, examining a one-to-one moral dilemma where the lives of AV occupants are weighed against those of non-in-vehicle pedestrians presents inherent challenges in systematic analysis. The choices made in these situations can lead to adverse consequences for car occupants, other road users, and pedestrians (Kallioinen *et al.*, 2019). This dilemma directly highlights the moral conflict between self-preservation (protecting oneself) and pro-social behaviour (protecting others). Bonnefon *et al.* (2016) proposed a scenario involving an AV with a single passenger, confronted with the decision to steer towards an unmovable barrier or continue on the current path and collide with a pedestrian. The results indicated a preference for prioritising human lives based on factors such as age, gender, and social status.

3. Research Approaches

The survey strategy entails the use of web-based questions to query and understand respondents' perspectives on AV decision-making in Singapore. An online self-completion questionnaire has been utilised, as shown in the Appendix. Descriptive analysis results on the SP survey questionnaires regarding the attitudes of the respondents and their preferred moral decision-making model for AVs when confronted with a moral dilemma. Individual *t*-tests were adopted to clarify whether are significant differences in the expected moral model development, i.e., Questions 4-6 in the Appendix, among the attributes, such as gender, AV design and hazard perception of respondents listed in Questions 1-3, respectively.

In addition, this study further discusses the potential influences of personal/emotional connection with AVs, insurance motivation, and legal liability on the decision-making of moral model determination by using Questions 8-10. The questions were aimed at probing respondents' attitudes and preferred AV moral decision-making models when faced with moral dilemmas, as shown in Table 1.

AV DECISION-MAKING MODELS	ENCODING VALUE
Random choice	1
Moral norms of car owner learnt by A.I.	2
Moral model developed by A.I.	3

Table 1: AV Decision-Making Models

Random choice refers to AV modelling their decision-making using random choice. Moral norms of car owners learnt by A.I. indicate AV modelling their decision-making based on AV owner's decisions. Moral norms developed by A.I. denote AV manufacturers modelling their decision-making based on the A.I. algorithm.

Moreover, discriminant analysis was utilised in this study to classify the respondents' preference in AV moral model determination based on the diversity of their individual attributes. Discriminant analysis refers to a multivariate technique to distinguish between two or more sets of observations considering *k* variables that are measured for each experimental unit, ultimately determining the significance of each variable's role in the separation of these groups.

Equation 1 lists the linear discriminant function, where Z_{jk} refers to the discriminant *Z* score of discriminant function *j* for object *k*, W_i refers to the discriminant coefficient for independent variable *i*, and X_{ik} refers to the independent variable *i* for object *k*.

$$Z_{jk} = \sum_{i=1}^{n} W_i X_{ik} \quad (1)$$

A major limitation of discriminant analysis is the fact that it requires more observations than variables and the predictors to be independent (Buzzini *et al.*, 2021). Thus, correlations between all variables measuring multicollinearity were analysed prior to conducting discriminant analysis.

4. Results and Discussions

The survey responses were derived from 108 unique respondents, including 64 female and 44 male respondents. 92.59% of respondents agreed that a well-designed autonomous vehicle should minimise human casualties, whereas only 8 respondents disagreed. Furthermore, there were 54.63% of respondents preferred to minimise pedestrian casualties, while 49 respondents suggested protecting the AV occupants.

Table 2 lists the results of individual *t*-tests with the assumption of non-equal variances for Questions 4-6. Table 2 reveals that there is no difference in perception of the A.I. moral algorithm between male and female respondents. In the context of AV design, the level of conviction among respondents, who agree that a well-designed AV should minimise human casualties, believing that “the AV moral dilemma model developed by the A.I. would make a better decision than random choices” is stronger than that among respondents who hold the opposing view.

Moreover, respondents who prioritised safeguarding pedestrians from casualties exhibit less confidence in the AV's ability to decide whose life should be sacrificed even if it proposed a good A.I. moral model, in contrast to those respondents who prioritised the well-being of occupants in AVs, at the significance level $p < 0.1$.

Perception of A.I. moral algorithms	Groups	*t*-value	Sig. (2-tails)
A.I. algorithm will be better than random (Question 4)	Gender (Question 1)	0.678	0.500
	AV design (Question 2)	-2.408	0.044**
	Hazard perception (Question 3)	-0.668	0.505
Consensus built by humans (Question 5)	Gender (Question 1)	0.246	0.806
	AV design (Question 2)	-1.166	0.280
	Hazard perception (Question 3)	-0.738	0.462
A.I. is unable to decide (Question 6)	Gender (Question 1)	-0.703	0.484
	AV design (Question 2)	0.522	0.616
	Hazard perception (Question 3)	1.849	0.068*

** $p < 0.05$; * $p < 0.1$

Table 2: Analytical Results of the *t*-test

Figure 1 illustrates respondents’ preference in the AV decision-making models among the different scenarios. If the AV was able to build emotional connections with respondents, e.g., communicating with in-vehicle occupants, making recommendations, or assisting in their decision-making process, 61.11% of respondents preferred the AV decision-making model to be the moral norms of car owners learnt by A.I.

If insurance companies provided policyholders with a 40% rebate in insurance premiums for AVs, 51.85% of respondents still preferred the AV decision-making model to be the moral norms of car owners learnt by A.I. However, the response count for “the AV decision-making model to be the moral model developed by A.I.” increased drastically from 26.85% to 43.52%. Thus, a reduction in insurance premium was 16.67% effective in incentivising a warmer reception towards a moral model developed by A.I., whereas the random choice possesses the lowest preference of less than 5%.

If AV owners were held criminally liable for accidents if their AV’s decision-making model was that of moral norms of car owner learnt by A.I., but would be exempted if their AV’s decision-making model was either of random choice or moral model developed by A.I., then 45.37% of respondents most preferred the AV decision-making model would be the moral model developed by A.I., while 17.59% of respondents prefer random choice. Thereby, the result shows that legal liability is successful in inducing a shift in the respondents' preferences towards an AI-developed moral model as the decision-making model for AVs.

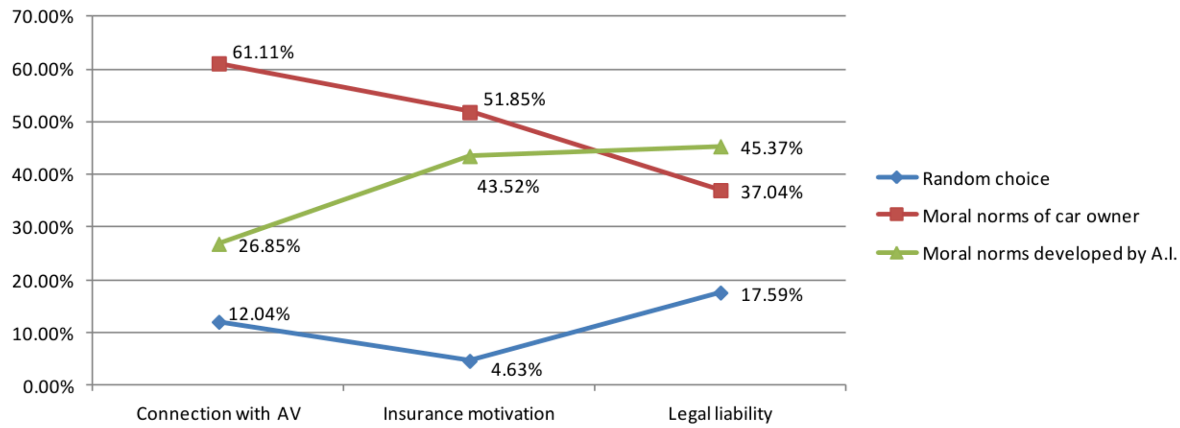

Figure 1: Preferences in AV Decision-Making Models

To investigate which respondents' attributes are most useful to discriminate among their 3 unique groups of preferred AV decision-making models, Question 7 was used to be the dependent variable, while Questions 1-6 were adopted as independent variables in the linear discriminant analysis. Table 3 represents the correlation matrix results of dependent variables, showing that the results exhibited a low occurrence of multi-collinearity, as the correlation coefficients were all below at least ± 0.50 recommended by Ratner (2009). This thus avoids the generation of unreliable predictive performance for the predictive model caused by high correlation among predictors (Daoud, 2017).

Correlation	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6
Question 1	1.000	0.091	0.041	-0.062	-0.017	0.069
Question 2	0.091	1.000	0.030	0.307	0.202	-0.043
Question 3	0.041	0.030	1.000	0.064	0.072	-0.156
Question 4	-0.062	0.307	0.064	1.000	0.475	-0.144
Question 5	-0.017	0.202	0.072	0.475	1.000	-0.140
Question 6	0.069	-0.043	-0.156	-0.144	-0.140	1.000

Table 3: Correlation Matrix Results

To improve the variable scaling and interpretability, we derive the standardised canonical discriminant function coefficients, where the Structure Matrix that displays the correlations between independent variables and the discriminant functions. Questions 1-6 refer to the independent variable *i* in Eq. (1), i.e., *i = 1, 2, 3, …, 6*, while the number of object *k* in this study is 108. Eqs. (2) and (3) show the results of the discriminant function.

$$Z_{1k} = 0.016X_{1k} - \mathbf{0.499X_{2k}} - 0.132X_{3k} + \mathbf{0.574X_{4k}} + \mathbf{0.627X_{5k}} + 0.029X_{6k} \quad (2)$$
$$Z_{2k} = -0.040X_{1k} + \mathbf{0.357X_{2k}} + \mathbf{0.425X_{3k}} + 0.011X_{4k} + 0.021X_{5k} - \mathbf{0.739X_{6k}} \quad (3)$$

The independent variables with coefficient values above ± 0.3 are considered important in this study, as they better discriminate between group memberships, as highlighted in bold in discriminant functions 1 and 2. Gender plays an insignificant role in both discriminant functions, this is consistent with the individual *t*-test results, whereas the trust in AV design for minimising human casualties plays a critical role in both discriminant functions, although the coefficients are in opposite signs.

In general, Z_{1k} is influenced negatively by X_{2k}, while it is influenced positively by X_{4k} and X_{5k}. In contrast, Z_{2k} is influenced positively by X_{2k} and X_{3k}, while it is influenced positively by X_{6k}. The results show that the respondents described by discriminant function 1 believe that the moral model developed by A.I. would make better decisions than random choices and it should be a strong consensus built by humans because they do not trust that AVs, even well-designed, are able to minimise human casualties. On the other hand, the respondents described by discriminant function 2 agree that well-designed AVs should prioritise minimising human casualties and are open to considering scenarios where the in-vehicle passengers' safety is endangered to prioritise minimizing pedestrian casualties but believe that A.I. can have the authority to decide whose life should be sacrificed based on a good moral model.

The classification results are provided in Table 4, which indicate an overall 56.5% accuracy in predicting the respondents' choices correctly on average, displaying moderately satisfactory predictive performance. Nonetheless, this arose due to the generation of imbalanced data since the majority of respondents' selections skewed towards the response "Moral norms of car owners learnt by A.I." for their preferred AV decision-making model.

Predicted / Count	Random choice	Moral norms of car owners	Moral norms developed by A.I.
Random choice	2	12	0
Moral norms of car owners	2	54	7
Moral norms developed by A.I.	0	26	5

Table 4: Classification Results

5. Conclusion

With the highest level of vehicle automation have a large potential to assist people in their daily lives. Nevertheless, in this case, where drivers' intervention and assistance are no longer needed, the moral dilemma arises since AV is the one who regulates its driving behaviour and makes decisions when a traffic accident happens. This study has utilised an SP survey in the context of Singapore to gather information about respondents' choices when they are faced with moral dilemma situations involving level 5 AVs.

In summary, the results suggest that the expectation level for AVs can affect the beliefs in the A.I. algorithms handling moral dilemmas, whereas respondents' gender does not significantly influence the attitudes of respondents towards the development of decision-making models for AVs. The results also show that rebates in insurance premiums and legal liability were effective in engendering a change in respondents' preferences towards a moral model developed by A.I. as the AV decision-making model. Moreover, two groups regarding the expectation for AV are identified based on the discriminant analysis.

The study suggests that individuals' expectations concerning AVs play a pivotal role in shaping their beliefs about the efficacy of A.I. algorithms in handling moral dilemmas. As people's anticipation of AV capabilities rises, so does their confidence in A.I.'s decision-making. Therefore, manufacturers and developers should not only focus on technological advancement but also manage and set appropriate expectations for AVs to foster positive attitudes towards A.I. moral algorithms.

The study underscores the effectiveness of offering rebates for insurance premiums and addressing legal liability concerns in shifting respondents' preferences towards accepting A.I.-developed moral models for AVs. This implies that tangible benefits can serve as powerful motivators for individuals to embrace innovative technologies and ethical decision-making frameworks. Policymakers and companies should consider implementing such incentives to promote positive behavioural shifts.

The analysis reveals two distinct belief groups: one group that distrusts AVs' ability to minimise human casualties and seeks a strong consensus driven by human decisions, and the other group that is more open to AVs prioritising human safety, even if it means endangering in-vehicle passengers. Understanding these belief clusters can guide targeted communication efforts. The first group may need reassurance about the human role in ethical decision-making, while the second group could benefit from information emphasising the potential of A.I. moral models.

This study is limited to the fact that level 5 AVs are not yet reached marketability in Singapore. Thereby, an SP survey, instead of a revealed preference survey, was employed, in which respondents might overstate their valuation or expectation of a particular good, service or outcome. Accordingly, future studies are recommended to conduct a revealed preference survey in the context where sufficient level 5 AV-related data is available. In addition, more advanced statistical modelling can be applied to further investigate respondents' behaviour when they are faced with AV-involved moral dilemma situations.

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Appendix

This document provides key information on the Moral Dilemmas Facing an Autonomous Vehicle Research Project that you have been invited to participate in. Your participation is voluntary but very important to the advancement of knowledge in the human-machine interface of autonomous vehicle (self-driving car) applications in Singapore.

> With this study, we would like to examine the moral dilemma facing a level 5 autonomous vehicle. There is NO pedals and steering wheel in a level 5 autonomous vehicle (or self-driving car), leading to the impossibility for humans to intervene. Waymo, developed by Google, is an example of a level 5 autonomous vehicle. Similar to trolley dilemmas, there would be moral dilemmas if an autonomous vehicle experiences a sudden mechanical failure (e.g., brake failure). Staying on course would result in the death of pedestrians, whereas swerving would endanger in-vehicle passengers. When the harm is unavoidable, how an autonomous vehicle should decide on behalf of human becomes critical.

Part I

1.	Gender	□ Male	□ Female
2.	Do you agree that a well-designed autonomous vehicle should minimise human casualties?	□ Agree	□ Disagree
3.	Would you consider an autonomous vehicle, which might endanger the in-vehicle passenger (i.e., you) but minimise pedestrian casualties?	□ Yes	□ No

Part II

		Strongly disagree	Disagree	Undecided	Agree	Strongly agree
4.	I think the moral model developed by Artificial Intelligence (A.I.) for the autonomous vehicle dilemma would make a better decision than random choices.	□	□	□	□	□
5.	Using the moral model developed by A.I. to solve the autonomous vehicle dilemma would be a strong consensus built by humans.	□	□	□	□	□
6.	I do NOT think A.I. is able to decide whose life should be sacrificed even if it proposed a good moral model.	□	□	□	□	□

7. Which of the following decision logic for an autonomous vehicle facing a moral dilemma is most accepted by you? (**Select only one**)

   □ Random choice □ Moral norms of car owner learnt by A.I. □ Moral model developed by A.I.

8. When you travel in the self-driving car, the virtual assistant of your autonomous vehicle would chat with you, answer your questions, make recommendations, and assist your decisions. Assume that you trust and

emotionally connect with your autonomous vehicle. (**Select only one**)

□ Random choice □ Moral norms of car owner learnt by A.I. □ Moral model developed by A.I.

9. If insurance companies inform you that you can enjoy 40% off in insurance premium of your autonomous vehicle policy when the moral model developed by A.I. is adopted, which of the following decision logic would you prefer? (**Select only one**)

   □ Random choice □ Moral norms of car owner learnt by A.I. □ Moral model developed by A.I.

10. If the Act containing regulations for autonomous vehicles indicates that after an incident involving an AV, the owner should be investigated if he/she decides to follow the moral norms of car owners as the decision logic, whereas the owner is exempted from criminal liability if he/she adopted random choice or moral model developed by A.I. Based on the situation, which of the following decision logic would you prefer? (**Select only one**)

    □ Random choice □ Moral norms of car owner learnt by A.I. □ Moral model developed by A.I.