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Influencing Factors of Driving Decision-Making Under the Moral Dilemma

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ABSTRACT Autonomous vehicles (AVs) are supposed to make appropriate strategies to ensure driving safety and improve traffic efficiency. However, not all collisions will be avoidable. In a typical dilemma scenario of this paper, we have to make hard decisions from two evils, sparing a child with red-light running behavior or crashing into a well-equipped motorcycle driver without violation of the traffic law. Combined with the existing traffic laws and the accident liability judgment cases in China, 12 typical dilemma scenarios are established. In order to acquire data to analyze the driving decision-making factors involving ethics and legal under the moral dilemma of AVs, we conduct a series of experiments in virtual reality environments. Furthermore, key factors are extracted to characterize the driving decisions under different scenarios and quantified by the gray relation entropy analysis method. Particularly, the ethical factor is represented by the quantity and type of collision targets, the legal factor is qualified by rights of way. The results showed that priority levels of the influencing factors in each moral dilemma were considerably different. Nevertheless, when the quantity of collision targets on two sides is equal, more participants prefer to protect the ones that comply with traffic rules. The research results can provide the basis for designing moral algorithms for the AVs.

INDEX TERMS Autonomous vehicles, accident liability, driving decision-making factor, gray relation entropy analysis, moral dilemma.

I. INTRODUCTION

Recently autonomous vehicles (AVs) have become a hot topic in the field of transportation. Featured with innovative technologies, such as environmental perception, automatic control, and artificial intelligence, AVs can sense the environment in real time, realize intelligent decision-making, and avoid obstacles in advance, so as to considerably reduce traffic accidents [1]–[6]. Nevertheless, in most cases due to dead zones, object transparency, light reflection, weather conditions, sensor failure, and even sudden entry of object, AVs may encounter with inevitable crashes under the emergency situations [7]–[9]. In this case, the human driver can choose the collision target according to his own experience

to reduce losses as much as possible. However, as for AVs, the decision-making system and ethical algorithm should have been set in advance. Accordingly, the most pressing issues that need to be addressed include ethical decision-making, ethical responsibility distribution, as well as broader ethical problems brought about by emerging technologies in dilemma situations [10]. Waldrop insisted that if there were no clear ethical rules to guide AVs, it would be difficult to change the current distrust situations of users. Meanwhile, customers would be less willing to buy such an AV [11]. This issue, a rather controversial one, has engendered a heated debate among the manufacturers, ethics experts, government regulators, and consumers.

Under the moral dilemma, in order to make the decision of AVs in line with the human mind, it is necessary to study the decision mode of well-behaved human drivers

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initially and clarify the main influencing factors of decision-making. It is generally believed that the factors affecting driving decision-making mainly include driver-vehicle-road-environment ones. The factors are coupled with each other, whose relationship is complex and changes in real time. Meanwhile, positive and negative feedback between them jointly determines the decision-making. So far, the current researches have focused on decision-making under normal driving conditions and have attained mature results. As for the aspect of drivers, the propensity of drivers is the main factor affecting driving decision-making behavior. It is the comprehensive manifestation of drivers' physiological and psychological characteristics [12], which includes age [13], gender [14], emotion [15], risk perception [16], attitude [17], driving characteristic [18], cognitive features [19], habit [20], attention features [21], driving ability [22], and task properties [23]. In terms of vehicles, vehicle motion state [24] and performance is the main factor affecting decision-making. From the perspective of road-environment factors, they can be divided into three categories: external weather environment, road driving environment, and cockpit environment. External weather environment refers to the unpredictable weather, such as ice, snow, rain, fog, etc. [25], [26] Road driving environment includes road alignment [27], road facilities [28], [29] and roadside environment [30]. Cockpit environment contains the physical environment (such as temperature [31], [32], noise [33]) and driving sub-tasks (such as using the cell phone [34], listening to the radio [35], [36]). These vehicle-road-environment factors will have an indirect effect on the driver's behavior, psychological and physiological state, and ultimately affect the reliability of driving decision and driving safety. Further study on driving decision-making influence factors helps to scientifically select the main factors and the mechanism of different driving behavior patterns. Still, in a moral dilemma, ethics is too abstract to quantify. Previous research has failed to study the impact factors of driving decision-making in the moral dilemma.

Apart from the above influencing factors, ethics and legal have become another two significant factors affecting decision-making in the moral dilemma [37], [38]. Ethics refers to the norms of people's internal values and external behavior [39], [40], which can be represented by some specific indicators. Moral Machine [41] distinguished millions of scenarios according to many indicators, such as the type of collision target, the number of collision targets and whether to give priority to the protection of passengers. At the same time, when it comes to making decisions in moral dilemmas, there is an ethical argument for AVs to act in a deontological or utilitarian way [2]. Similar to Asimov's laws of robotics [42], deontological ethics restricts the decision-making of AVs to clear rules. Thornton *et al.* proposed three rules of AVs [3], which clearly defines the protecting priority and the avoidance order of pedestrians, vehicles and other objects. Meanwhile, utilitarianism advocates that the total damage caused by accidents should be minimized [43]. It indicates that an AV needs to convert various potential collision targets into life

utility values, and eventually the AV will hit the target with the lowest one. However, both deontological and utilitarian ignore to protect innocent law-abiding pedestrians, which may even be used by lawbreakers to make AVs a new criminal tool.

Consequently, the legal factor matters as well. As soon as an AV encounter with collisions in a moral dilemma, it will be identified as a traffic accident. Furthermore, the traffic management department will judge the driver's liability in the accident according to the relevant legal documents. The specific results are directly related to the driver's decision-making and the behavior of each target involving the scene [44], such as the illegal behavior of the collision target and an AV retrograding into the opposite lane. So far, many scholars have carried out a series of studies around these two factors.

As for ethical perspective, ethical decisions by AVs are often discussed on the basis of trolley dilemmas [45], where we must decide whether to change the direction of a trolley that will sacrifice one individual to spare five non-different homogenous individuals. Then ethicists introduce changeable variables to make the dilemma moderately complicated. For instance, they took into account the characteristics of the individual, such as children, pregnant women, the elders, and animals [46], [47]. Lin [48] designed the corresponding scenarios to discuss the moral difficulties faced by AVs in possible accidents. Meanwhile, he discussed how AVs should choose between two evils by changing the type of collision targets, such as wild deer frequently appeared on American highways, pedestrians or motorcycles with different protective equipment, and even a large number of children with red-light running behaviors. On the contrary, Sven Nyholm [39] objected to this, arguing that the moral dilemma faced by AVs is different from the "trolley dilemmas". The former involves manufacturers, vehicle owners, regulators, and other stakeholders to decide how to design an accidental algorithm, whereas the latter only involves individual moral choices. In addition, the moral decision of the former will directly bear the ethical and legal responsibility of the accident. In terms of moral principles, the latter only involves crashing into the majority or the minority, whereas the former involves sacrificing vehicle owners or pedestrians. Moreover, Edmond [41] challenged the high dimensionality of the moral dilemma of AVs. They identified three strong preferences which can be served as a cornerstone to discuss the problem all over the world: giving priority to spare human lives, more lives, and young lives.

As far as legal research is concerned, the law is the baseline of ethical standards. Legal can provide a guide for the development of ethical artificial intelligence. Attributed to the moral algorithm, Awad [41] raised a serious question on whether we need to protect illegal pedestrians. Compared with other ethical priorities, protecting individuals with illegal behaviors is less of a priority. Globally, a typical survey manifested participants from poorer and less legally conscious countries were more tolerant of people behave

illegally. Presumably, because of their lower compliance with the rules, society has a weaker punishment for rule deviation [41], [48]. Li *et al.* introduced the legal factors into the driving decision-making model under emergency situations evoked by red light-running behaviors[40]. Three indicators were selected, the duration of red light (RL), the type of abnormal target (AT-T), and the state of the abnormal target (AT-S), which indicates legal components. In a word, the above study only considered either the ethical or legal factor, both of them had a significant impact on decision-making and could not be ignored. In fact, the preferences for ethical algorithms vary widely from cultures, regions, and races [41]. It is significant to modify it combined with the Chinese way of thinking and the accident liability judgment system of the Chinese traffic law.

Derived from these findings, this paper highlights two typical driving decision-making factors in the moral dilemma, ethics and legal. Combined with the relevant legal documents of China’s traffic, the accident liability is divided into collision results caused by different decisions in specific scenarios. The ethical algorithm should be guided by the justice of the law. It reflects the correcting effect of legal on ethical decision-making algorithm and will be argued for an ethics setting implemented in AVs.

The remainder of the paper is organized as follows. Sec. 2 introduces the gray relation entropy analysis method. Sec. 3 describes the virtual reality (VR) experiment. Twelve moral dilemma scenarios are listed as emergency situations, where collisions will not be avoidable. The qualitative analysis is reported in Sec. 4. We identify the traffic accident liability for each scene and integrate ethics and legal into the influencing factors of decision-making. In Sec. 5, the experimental data are qualitatively and quantitatively calculated to determine the degree of influence of various factors on decision-making. Sec. 6 analyzes and compares the driver decision-making in experiment. Finally, Sec. 7 concludes our work.

II. GRAY RELATION ENTROPY ANALYSIS METHOD

There are a number of factors influencing driving decision-making in the moral dilemma. In order to avoid the overlap of multi-variable caused by multi-collinearity, it is significant to analyze and extract the main influence factors of driving decision.

The methods of multi-variable analysis mainly include regression analysis, variance analysis, principal component analysis, and other statistical methods. Although these methods can solve many practical problems, they often have shortcomings such as the pursuit of large samples, the requirement of sample obeying the typical distribution, the large amount of calculation, and sometimes the discrepancy between quantitative results and qualitative analysis. However, the gray relation entropy analysis method overcomes the shortcomings of the above methods. Especially to solve the problem on large gray scale samples with a limited number and no typical distribution rules, the method has wide practical value.

At the same time, due to the different physical meanings of weights and dimensions, the indicators of driving influence factors are not collinear and it is difficult to make direct comparisons. There are many methods for determining weights at present, but the vast majority of them are subjective. Using the gray relation entropy to analyze the weight of the indicator, the human factor can be eliminated to the maximum extent. Accordingly, the gray relation entropy analysis method is used to extract and sort the main influence factors of driving decision.

A. DETERMINE THE MAPPING QUANTITY

In order to analyze an abstract system, first of all, we should select the data sequence that reflects the characteristics, that is, find the mapping quantity of the system, and use it to represent the system indirectly. The selection of mapping variables should follow the principles of functionality, accessibility, integrity, comparability, and non-overlap [12].

B. HOMOGENIZATION

Suppose $X_0^* = [X_0^*(1), X_0^*(2), \dots, X_0^*(n)]$ as the reference column, the driving decision-making influencing factors are taken as the comparative sequences, that is $X_j^* = [X_j^*(1), X_j^*(2), \dots, X_j^*(n)]$, $j = 1, 2, \dots, m$. The original data were processed dimensionless according to the Equation (1) and (2).

$$X_0(k) = X_0^*(k)/X_0^*(1) \tag{1}$$

$$X_j(k) = X_j^*(k)/X_j^*(1) \tag{2}$$

where, $k = 1, 2, \dots, n, j = 1, 2, \dots, m$.

Then we get the dimensionless reference column $X_0 = [X_0(1), \dots, X_0(n)]$, and dimensionless comparison columns $X_j = [X_j(1), \dots, X_j(n)]$.

C. CALCULATION OF GRAY RELATION COEFFICIENT

The absolute difference between the reference column and the comparison column in the data k point is denoted as $\Delta_{jk} = |x_0(k) - x_j(k)|$. We use Δ to represent the sum of all the differences, as shown in Equation (3).

$$\Delta = \left[\sum_{j=1}^m \sum_{k=1}^n |x_0(k) - x_j(k)| \right] / (m \times n) \tag{3}$$

Pick the maximum and minimum of: Δ_{jk}

$$\Delta_{\min} = \min_j \min_k |x_0(k) - x_j(k)|$$

$$\Delta_{\max} = \max_j \max_k |x_0(k) - x_j(k)|$$

Then the gray correlation coefficients of x and y at k point is shown in Equation (4):

$$\xi_{jk} = \frac{\Delta_{\min} + \rho \Delta_{\max}}{|x_0(k) - x_j(k)| + \rho \Delta_{\max}} \tag{4}$$

$\rho \in (0, 1)$ is the resolution coefficient to simplify the calculation, generally, take $\rho = 0.5$. In practical application, the value of ρ is calculated and adjusted according to the

correlation degree of each time series, in order to obtain better resolution ability. The principles for the value of ρ are as follows:

$$\rho \begin{cases} \varepsilon \leq \rho \leq 1.5\varepsilon, \Delta_{\max} > 3\Delta \\ 1.5\varepsilon \leq \rho \leq 2\varepsilon, \Delta_{\max} < 3\Delta \end{cases} \quad (5)$$

where ε is the ratio of the mean to the maximum difference:

$$\varepsilon = \Delta / \Delta_{\max} \quad (6)$$

D. CALCULATION OF GRAY RELATION ENTROPY

In Equation (6), P_{jh} is the distribution mapping of the gray relation coefficient. Then the gray relation entropy is shown in Equation (7).

$$H_{jh} = - \sum_{h=1}^n P_{jh} \ln(P_{jh}) \quad (7)$$

E. EVALUATION OF GRAY ENTROPY CORRELATION DEGREE

The gray entropy correlation degree of each comparison column is defined as followed.

$$E_{jh} = H_{jh} / H_m \quad (8)$$

$H_m = \ln(n)^n$, is the number of elements.

Accordingly, the ranking rule of the gray relation sequence is obtained. The higher entropy correlation degree of the comparison column is, the stronger the correlation between the comparison column and the reference column is, and the greater the influence on the reference column will be.

III. VR EXPERIMENT

A. SCENARIOS DESIGN

There are many factors that affect driving decision-making, among which the change of scenarios is an essential aspect. It is necessary to rely on the scenarios to analyze the driver's decision-making behavior. Therefore, in this paper, twelve scenarios are designed to contrast each other and aim to highlight the role of ethics and legal in driving decision-making. Scenario A sets four different types of collision targets, children, adults, well-equipped motorcycle drivers, and motor vehicles. Scenario B adds the crosswalk and traffic lights compared with scenario A, while scenario C changes the number of collision targets compared with scenario B. The driver needs to choose between braking and braking + turning left. In each scene, the guardrail is set up to protect pedestrians in the sidewalk, and this paper does not consider the driver choose to crash into the guardrail (brake+ turn right) to sacrifice themselves.

The details of each scenario are described as followed.

In scenario A, the road with 2-lane 2-way is set. The red vehicle is driving normally. There is a child (or adult) crossing the road. At this time, there is a motorcycle (or motor vehicle) driving in the opposite lane. Motorcycle drivers wear protective equipment and drive normally without violation of the traffic law.

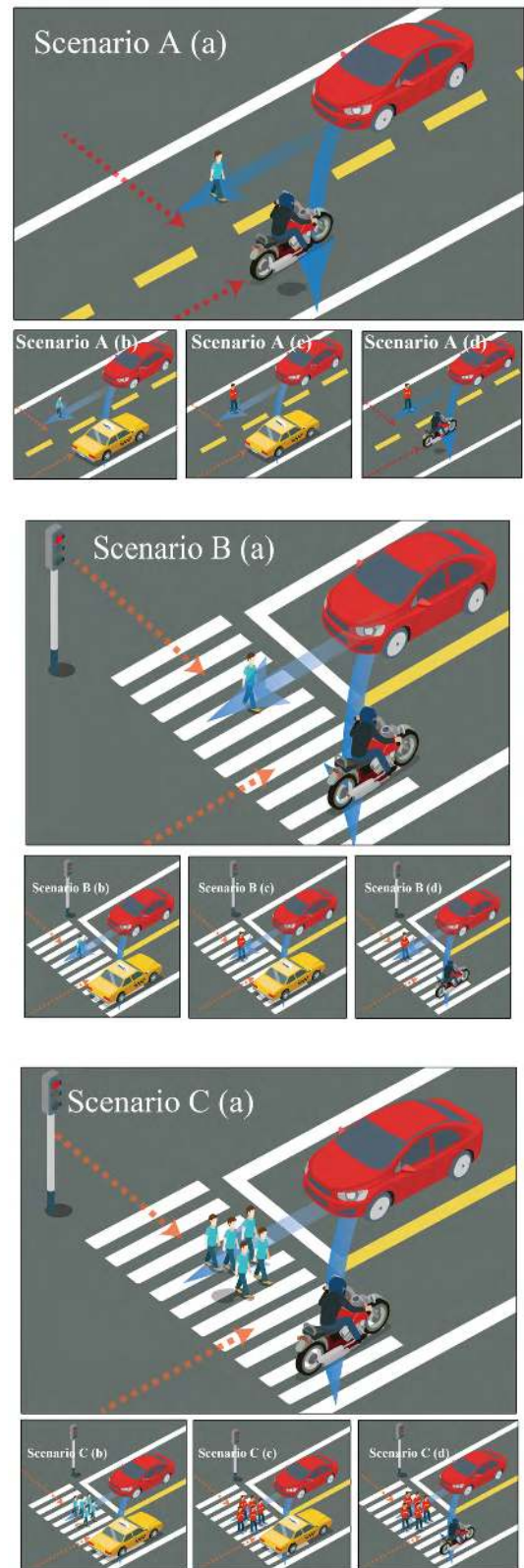


FIGURE 1. Twelve moral dilemma scenario.

In scenario B, a child (or adult) suddenly is crossing the road with the red light on. The other element is the same as scenario A.

In scenario C, the number of ones with red-light running behavior is increased to five. The other element is same as scenario B.

When the volunteers are about to arrive at the intersection, we can control the abnormal targets and the adjacent lane vehicles, and artificially create emergency situations.

B. EXPERIMENT EQUIPMENT

Driving decisions and scenarios are highly relevant. In order to demonstrate the role of morality and legal factors in decision-making, in this paper we select typical scenarios, use UC-win/Road 13.0.1 software to model virtual scenes and access the FORUM 8.0 driving simulator for driving decision virtual experiments. The simulator can record the position coordinates, velocity, and acceleration of the target vehicle and the surrounding vehicle in real time.

C. PARTICIPANTS

60 drivers (aged from 25 to 50; $M = 29.9$, $SD = 4.3$; 48 males and 12 females) were recruited for the experiment. All participants were required to have more than three years of active driving experience with a valid license and a minimum 10,000 km of total driving distance during the past three years. Among the 60 participants, three (two men and one woman) had been involved in a minor accident in the past five years, and the others never had any car accident before.

D. EXPERIMENT PROCESS

1) ADAPTIVE TRAINING

The driver needs to perform adaptive training before the formal experiment. In order to make the participants more familiar with the platform, such as accelerating, steering, and braking. The participants were arranged to drive on a relatively wide highway, who need to avoid three obstacles. During the experiment, it was found that the minority had the simulator adaptive syndrome (SAS), and even some may even have motion sickness reaction. For those who are not suitable for the simulator, they will generally suspend their subsequent experiments to ensure their health and more reliable for the experimental data.

2) DECISION-MAKING EXPERIMENT UNDER THE EMERGENCY SITUATIONS

Without warning of what is about to happen, participants were required to drive along the designated urban roads. When the driver reached the trigger point, the staffs controlled the pedestrians on running from the side of the road and stop in the middle of the road. In this process, the driver may take measures such as braking and steering. They would make a decision from two evils, colliding with pedestrians or motorcycles (or motor vehicle).

3) IDEAL DECISION UNDER EMERGENCY SITUATIONS

Due to the particularity of moral algorithm, volunteers need to make judgments from the perspective of bystanders to



FIGURE 2. VR driving experiment and screenshots of the VR environment in a random scenario.

avoid tension, lack of time and other problems that influence the experimental results. The above experiments would be performed again, and the driver's new record on braking, steering, and vehicle dynamics data were saved.

E. DATA COLLECTION

The specific collection process is divided into the following two parts:

1. Number all the participants in the experiment, and collect demographic information such as gender and age.
2. The collected data include driving trajectory data of the host vehicles which is obtained by UC-win/Road data output module. The time series data set is collected from 10 seconds before the host vehicle stops. The time interval for collecting data is 0.06 second. The collision targets selected by each participant are recorded by us. We select the driving data where the pedal brake value appears, which approximately shows the value of the decision made by the participants.

IV. QUALITATIVE ANALYSIS

A. QUANTIFICATION OF DRIVING DECISION FACTORS

Since this paper discusses the decision-making influence factors under the moral dilemma, the moral and legal factors in the scene of the driver are the focus of research. In order to make the research more targeted, an assumption is set up to simplify the experiment. The driver and the vehicle are considered as a unit. It is assumed that the reliability of the human-vehicle unit is substantially constant, and factors such as driver preference and complex urban traffic environment are not considered.

Under the premise of the above assumptions, combined with 12 kinds of moral dilemma scenarios, the factors affecting the decision-making in the scene are quantified, as shown in Table 1.

B. QUANTIFICATION OF LEGAL FACTORS.

The ethical influencing factors in driving decision-making are represented by the type of collision target and the quantity of collision target.

The legal factors in the scene are the type front target, the type of left target, rights of way. The rights of way are determined by the signal lights in the scene and the location of pedestrians crossing the street.

Under the moral dilemma, the driving decision will inevitably lead to traffic accidents, and it is necessary to

TABLE 1. Quantitative results of driving decision-making influencing factors.

	Mapping name	Values
X (dimensionless)	Decision making: braking and turning left are marked as X ₁ and X ₂ , respectively.	Give X ₁ and X ₂ an initial value respectively, using the percentage of the corresponding number of records in the total number of records.
Y ₁ (dimensionless)	Gender: the number of males and females in the experiment staff are marked as Y ₁₁ , Y ₁₂ respectively.	Give Y ₁₁ and Y ₁₂ an initial value respectively, using the percentage of male and female drivers in the total.
Y ₂ (dimensionless)	Age: the age of the driver in the experiment, 25-35 years old is defined as the young (Y ₂₁), 35-50 years old is defined as the middle-age (Y ₂₂)	Give Y ₂₁ and Y ₂₂ an initial value respectively, using the percentage of the young and the middle-age in the total.
Y ₃ (dimensionless)	Type of the front target: refers to the type of target directly in front of the lane where the host vehicle is located. It is divided into children (Y ₃₁) and adults (Y ₃₂).	Give Y ₃₁ and Y ₃₂ an initial value respectively, using the percentage of record participants choosing to crash into children or adults.
Y ₄ (dimensionless)	Type of left target: refers to the target type of the left lane of the host vehicle, which is divided into motorcycle (Y ₄₁) and motor vehicle (Y ₄₂).	Give Y ₄₁ and Y ₄₂ an initial value respectively, using the percentage of record participants choosing to crash into motorcycle or motor vehicle.
Y ₅ (dimensionless)	Quantity of the target: refers to the quantity of target directly in front of the lane where the host vehicle is located. It is divided into 1 (Y ₅₁) and 5 (Y ₅₂).	Give Y ₅₁ and Y ₅₂ an initial value respectively, using the percentage of one individual and five individual in the total.
Y ₆ (dimensionless)	Right of way: refers to whether the target directly in front of the lane of the host vehicle has a legal right of way, which is divided into YES (Y ₆₁) and NO (Y ₆₂).	Give Y ₆₁ and Y ₆₂ an initial value respectively, using the percentage of the number of records in the total.
Y ₇ (km/h)	Velocity: refers to the velocity of the host vehicle before the drivers make decisions	
Y ₈ (m)	The distance (left): refers to the distance between the host vehicle and the left target before the drivers make decisions	Give the instantaneous value when the brake pedal value first appears.
Y ₉ (m)	The distance (front): refers to the distance between the host vehicle and the front target before the drivers make decisions	

analyze the liabilities of all parties in the accident. Due to the complexity of the identification process of accident liability in China, traffic police usually make a comprehensive

TABLE 2. The judgment of accident liability for each scenario.

Scen-ario	Decision-making	Liability			Legal basis
		Host vehicle	Pedestrian	Motorcycle or motor vehicle	
A	Braking				Clause NO.47 in Safety Law
	Braking +turning left	Major liability	Secondary liability		Identification of liability for Special Traffic Accidents (*)
B	Braking	Secondary liability	Major liability	No liability	
	Braking +turning left	Equal liability	Equal liability		Clause NO.38, 47, 62 in Safety Law
C	Braking	Major liability	Secondary liability		
	Braking +turning left	Secondary liability	Secondary liability		

* Beijing Traffic Accident Liability stipulates if a party drives a motor vehicle over the center line of a road or facilities that are prohibited to cross, and has a traffic accident with other vehicles or pedestrians, the driver of the motor vehicle shall bear full liability.

judgment based on the Road Traffic Safety Law of the People Republic of China (hereinafter referred to as the “Safety Law”), other relevant legal documents and the specific situation of the accident scene. Therefore, in order to intuitively reflect the role of legal in decision-making, accident liability is sorted in descending order, that is major and above liability, major liability, equal liability, secondary liability, and no liability. In this paper, the identification of accident liability mainly refers to real cases similar to the scene. The distribution of accident responsibility for each target in each scenario is shown in Table 2.

V. EXPERIMENT RESULTS

A. EXPERIMENTAL DATA

The experimental data were quantified according to Table 1, and the results were shown in Table 3.

B. QUALITATIVE ANALYSIS

In order to further explore the role of moral and legal factors in decision-making, we designed two comparative schemes. The first scheme is to combine the experimental data in scenario A and scenario B. The second scheme is to combine the experimental data in scenario B and scenario C.

In the first scheme, the right of way (Y₆) is obviously different, but the quantity of the target (Y₅) is the same, therefore, Y₅ can be abandoned. On the contrary, in the second scheme, the value of Y₅ changed significantly, and Y₆ was abandoned because of the same value.

The basic rule of gray relation entropy analysis is to judge whether the two factors are closely related according to the similarity of the curve geometry of the changing trend of each factor. The more similar the curves are, the greater the relevance of the corresponding sequence will be.

TABLE 3. Quantitative results of experimental data.

Number	X	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9
1	0.386	0.700	0.750	0.210	0.290	0.883	0.670	38.723	23.727	11.454
2	0.614	0.300	0.750	0.180	0.320	0.883	0.330	22.105	15.020	6.676
3	0.386	0.700	0.250	0.210	0.290	0.117	0.670	58.656	17.480	10.357
4	0.386	0.700	0.750	0.210	0.290	0.883	0.670	46.377	20.611	6.968
5	0.614	0.700	0.750	0.210	0.290	0.883	0.670	43.721	20.036	10.853
6	0.386	0.700	0.750	0.210	0.320	0.883	0.330	34.042	26.846	6.719
7	0.614	0.700	0.750	0.180	0.320	0.883	0.330	61.973	26.963	8.214
8	0.386	0.300	0.750	0.180	0.290	0.883	0.670	63.413	18.849	9.823
9	0.386	0.300	0.750	0.210	0.320	0.883	0.330	28.785	19.403	10.703
10	0.386	0.700	0.750	0.210	0.290	0.883	0.670	56.851	20.729	8.125
...
357	0.614	0.700	0.750	0.180	0.290	0.117	0.670	33.999	26.250	9.607
358	0.614	0.700	0.750	0.180	0.320	0.883	0.670	24.582	23.337	7.620
359	0.614	0.700	0.250	0.180	0.320	0.883	0.670	62.973	26.035	10.570
360	0.386	0.700	0.250	0.210	0.320	0.883	0.330	44.826	21.517	11.478

TABLE 4. The sequence of each influencing factor after data processing in the scenario A and B.

Number	X-Y ₁	X-Y ₂	X-Y ₃	X-Y ₄	X-Y ₆	X-Y ₇	X-Y ₈	X-Y ₉
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.571	0.000	0.000	0.000	1.030	0.368	0.034	0.045
3	0.571	0.000	0.167	0.094	1.030	0.310	0.065	0.222
4	1.162	0.591	0.424	0.684	0.591	0.677	0.737	0.787
5	0.591	0.591	0.424	0.591	0.591	0.962	0.783	0.888
...
240	0.571	0.000	0.167	0.094	0.000	0.140	0.223	0.017
Δmin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Δmax	1.162	1.257	0.591	0.684	1.030	1.151	0.966	1.021

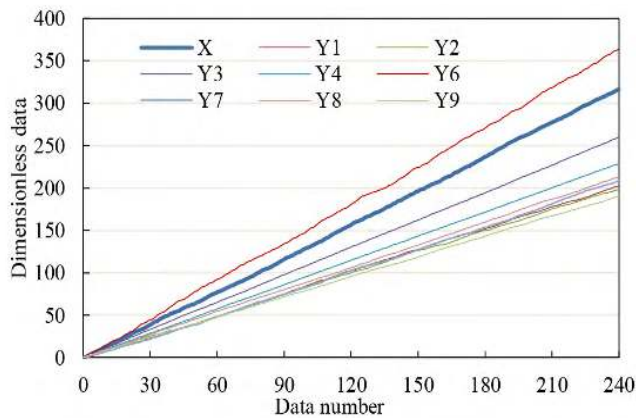


FIGURE 3. The trend of the reference column and each comparison column in the scenario A and B. The abscissa represents the data number, the ordinate represents the dimensionless accumulative data, and the bold line represents X.

The experiment data were added in a dimensionless form according to Equation (1) and Equation (2) and compared the trend of driving decision (X) and each factor (Y₁-Y₉) in different schemes, as shown in Fig. 3 and Fig. 4.

In Fig. 3, according to the similarity of the geometric shape of the curve between the reference column and each comparison column, the influence degree of each factor on the driving decision is preliminarily determined as follows:

$$Y_6 > Y_3 > Y_4 > Y_7 > Y_9 > Y_8 > Y_1 > Y_2$$

In other words, the sequence is as follows: right of way > type of the front target > type of left target > velocity > the distance (front) > the distance (left) > gender > age

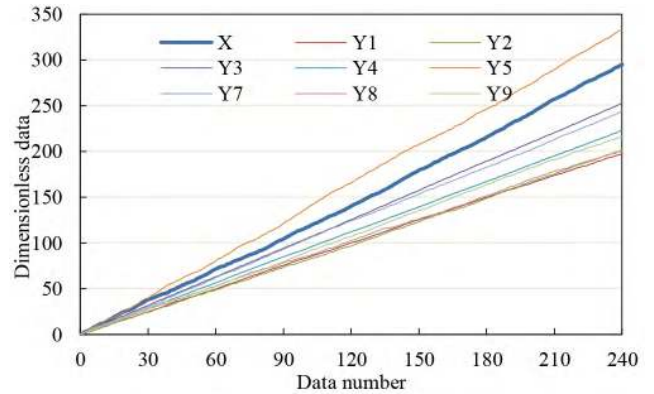


FIGURE 4. The trend of the reference column and each comparison column in scenario B and C.

Similarly, we can get the priority of each factor through Fig. 4 as follows:

$$Y_5 > Y_3 > Y_7 > Y_4 > Y_9 > Y_8 > Y_2 > Y_1$$

Namely, quantity of the target > type of the front target > velocity > type of left target > the distance (front) > the distance (left) > age > gender.

C. QUANTITATIVE CALCULATION

We calculated the dimensionless difference between the reference column and each comparison column in all experimental data, and get Δ_{max} and Δ_{min}, as shown in Table 4 and Table 5.

The value of ρ is determined according to Equation (3) and Equation (5), which is shown in Table 6.

TABLE 5. The sequence of each influencing factor after data processing in the scenario B and C.

Number	X-Y ₁	X-Y ₂	X-Y ₃	X-Y ₄	X-Y ₅	X-Y ₇	X-Y ₈	X-Y ₉
121	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
122	1.705	2.371	0.538	0.371	0.371	0.268	0.437	0.613
123	1.705	2.371	0.371	0.371	0.371	0.217	0.526	0.791
124	1.705	2.371	0.538	0.278	0.371	0.149	0.420	0.283
125	0.371	2.371	0.371	0.278	0.371	0.314	0.617	0.763
...
240	0.000	2.000	0.167	0.094	0.000	0.361	0.174	0.459
Δmin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Δmax	1.705	2.371	0.538	0.371	0.867	0.626	0.781	0.872

TABLE 6. Quantitative calculation results of the two comparison schemes.

Comparative data	Scheme1	Schemes2
Δmin	0	0
Δmax	1.257	2.371
Δ	0.4644	0.3615
ε	0.369	0.227
Range of ρ	0.554--0.739	0.227--0.341
Value of ρ	0.720	0.330

TABLE 7. Gray relation entropy of each comparing column in scenario a and B.

Gray correlation entropy	H(Y ₁)	H(Y ₂)	H(Y ₃)	H(Y ₄)
Value	5.352495	5.352495	5.352495	5.352495
Gray correlation entropy	H(Y ₆)	H(Y ₇)	H(Y ₈)	H(Y ₉)
Value	5.448606	5.448606	5.448606	5.448606

D. COMPARISON AND ANALYSIS

Taking $\rho = 0.720$ and $\rho = 0.330$ respectively, the gray relation entropy of each comparing column was calculated according to Equations (8) and (9), and the results are shown in Table 7 and 8. We can get the entropy correlation degree of each influencing factor according to Equation (8), as shown in Fig.5.

According to the value of entropy correlations, The results are consistent with the qualitative analysis. In the two schemes, Y₆ and Y₅ are the most important influencing factors respectively, which indicating that moral and legal factors have an important impact on driving decision-making.

The four factors of Y₁, Y₂, Y₈, and Y₉ have little influence on decision-making.

VI. ANALYSIS OF DRIVER DECISION-MAKING IN EXPERIMENT

A. TYPE OF THE COLLISION TARGET

Type of target can be divided into human beings, animals, motor vehicles, motorcycle, transportation facilities. At the same time, human beings can be further subdivided according to age, sex, physical condition, such as children, pregnant women, the elders, and the like.

TABLE 8. Gray relation entropy of each comparing column in scenario b and C.

Gray relation entropy	H(Y ₁)	H(Y ₂)	H(Y ₃)	H(Y ₄)
Value	5.322435	5.322435	5.322435	5.322435
Gray relation entropy	H(Y ₅)	H(Y ₇)	H(Y ₈)	H(Y ₉)
Value	5.468006	5.468006	5.468006	5.468006

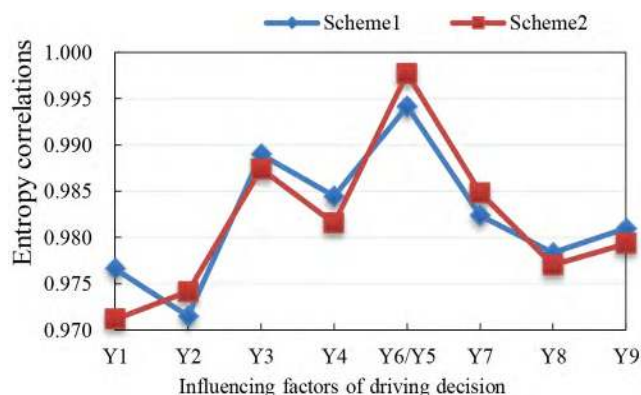


FIGURE 5. The entropy correlation degree of each influencing factor.

In scenario A, collision target is divided into children, adults, motorcycle, and motor vehicle. Overall, 67.5% of participants chose to spare the child and adult at the expense of crashing into motorcycles and motor vehicle. Among them, faced with motorcycles without violation of the traffic law, the majority choose to protect the child instead of adult. However, in the face of motor vehicles, there is no significant difference between choosing children and adults (Fig.6).

B. TYPE OF THE COLLISION TARGET VS. ACCIDENT LIABILITY

Compared with scenario A, scenario B deepens the elements that represent the legal in the dilemma. Scene B emphasizes the red-light running behavior of the child and adult. Accordingly, a number of volunteers who choose to protect the child and adult is significantly reduced. At the same time, more participants choose to spare an innocent motorcycle and motor vehicle, and the accident liability of the host vehicles is reduced (Fig. 7).

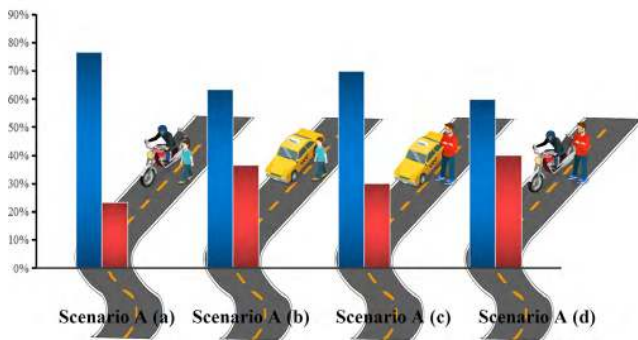


FIGURE 6. Percentage of different decisions in scenario A.

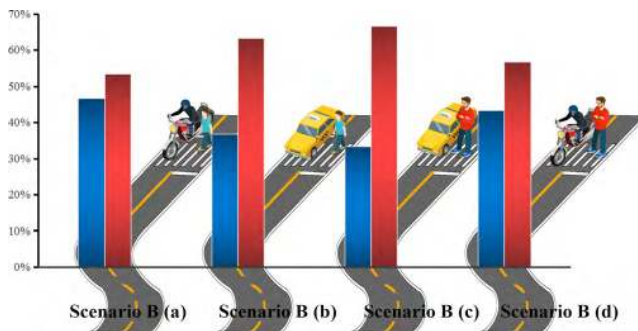


FIGURE 7. Percentage of different decisions in scenario B.

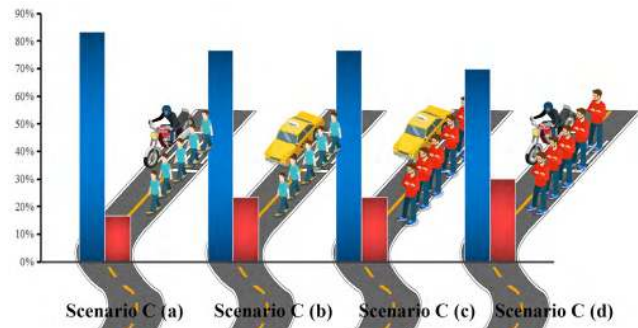


FIGURE 8. Percentage of different decisions in scenario C.

The test results of scenario A indicate that people choose to protect the pedestrian at the expense of well-protected motorcycle and motor vehicle. Both as drivers and bystanders, they tend to protect the pedestrian who is vulnerable to injury in accidents, however, adding into legal factors, more people will consider the accident liability before making a decision. As a result, some people have changed their previous decisions, hoping to minimize their accident liability and protect the innocents.

In scenario A, whether braking or turning left, the host vehicle takes the main liability, so more people choose to protect pedestrians. In scenario A, motor vehicles bear more liability than in scenario B. Due to the red-light running behavior of the pedestrian, the host vehicle bears less liability in scenario B so that more people choose to protect innocent people and give up protecting illegal groups.

Generally speaking, people are required to use the legal to restrict the decision-making behavior of AVs. After all,

no one wants to see an AV running into them at random. If we abide by the traffic rules and encounter the moral dilemma, more people think that there is no need to pay the price for the irresponsible illegal behavior of others, and should protect their own safety and interests. In the framework of ethical decision-making, the party responsible for the accident may need to be given priority as the target of the collision algorithm, meanwhile the innocent should be given maximum protection.

C. QUANTITY OF THE COLLISION TARGET VS. ACCIDENT LIABILITY

Compared with scenario C, scenario B highlights the impact of the quantity of targets on decision-making under the moral dilemma.

In scenario B, more volunteers chose to collide with the pedestrian with red light-running behaviors. Nevertheless in scenario C, when the number of violators significantly increases to five, most volunteers chose to collide with innocent motorcycle (or motor vehicle). In scenario C (a), only 5 participants target the higher number of children (Fig. 8). In scenario C (b) and (c), 7 participants target the group of five instead of the motor vehicle. In scenario C (d), 9 participants crash into 5 adults to spare the motorcycle. Therefore, in all four conditions, the majority of participants spare a larger number of pedestrians.

The quantity of collision targets is still the focus issue of driving decision under the moral dilemma. Utilitarianism, which advocates save more lives, is the most recognized rule to establish the moral algorithm of AVs. In scenario C, although the party who trigger the accident becomes five, the vast majority of participants prefer to protect the illegal groups, which is in line with the idea of utilitarianism, even neglecting the judgment of the accident liability. At the same time, the gray relation entropy analysis is concluded that life safety is set as the first decision sequence.

Unfortunately, utilitarianism does not represent the best decision-making in moral dilemmas. Even if the decision-making convinces most people, it often does not represent the true feelings of human beings. Therefore, in the process

of establishing ethical algorithms, it is necessary to use the justice of the law to protect the innocent group.

VII. CONCLUSION

In this paper, we address the influencing factors of driving decision-making under the moral dilemma and select 12 kinds of moral dilemma scenarios which are common in the urban traffic network. We identify the traffic accident liability for each scene and integrate ethics and legal into the influencing factors of decision-making. Furthermore, the gray relation entropy analysis method is used to deal with the experimental data, and the weight of each factor is calculated quantitatively.

The experimental results show that in the moral dilemma, the quantity of the collision target (Y_5) is the most important influencing factor of decision-making, and a large number of

participants tend to protect more lives, which is in line with utilitarianism approach. In addition, when the quantity of the target is same on both sides, whether the collision targets have the legal right of way (Y_6) becomes a more significant factor, indicating that most people will choose to protect innocent groups who abide by the law.

This paper provides a novel idea for solving the decision-making problem in the moral dilemma, and it will be argued for an obligatory ethics setting implemented in AVs. According to our research, we suggest that when faced with the moral dilemma, AVs should take account into the liability of all parties in the accident and give priority to spare innocent people.

However, with the complexity of this problem, especially in the case of significant individual differences, utilitarianism tends to fall into trouble. For example, the vulnerability of adults, children, and the elders are obviously different, passengers in the cockpit protected by safety measures and vulnerable pedestrians are distinctive as well. At the same time, specific quantitative injuries often cannot be described easily. Therefore, quantifying crash injury severity of collision target is the key to establish the ethical algorithm, which requires a lot of historical traffic accident data and experiments.

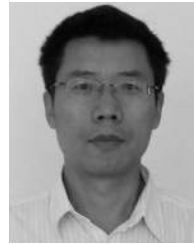
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