An Ethical Decision Making Algorithm for Autonomous Vehicles During an Inevitable Collision

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Abstract— **In this paper, we discuss ethical dilemmas in autonomous driving, focusing on the decision-making processes during an inevitable collision. Different from previous comparisons and applications concentrating on ethics, our paper, taking the right in constitution as the basis, innovatively incorporates the Robert Alexy's Weight Formula into the design of the ethical algorithm for autonomous vehicles. We also introduce a new formula for calculating survival rate, drawing on Rawls' Maximin Principle, with the goal of protecting the most vulnerable as much as possible. This new decision-making algorithm not only enables legal rights to be quantified in autonomous driving scenarios, but also provides fresh insights and algorithm design methods for solving ethical dilemmas. Through this innovative approach, we provide a more objective, reasonable and flexible framework for ethical decision-making in autonomous driving.**

I. INTRODUCTION

In recent years, advancements in technology have spurred ongoing development of intelligent vehicles by automobile companies. Society's acceptance of autonomous driving has been steadily increasing, and the sales of cars with assisted driving or autonomous driving functions have surged. However, due to some unsolved problems, the realization of fully autonomous vehicles remains uncertain. For example, in the design of autonomous driving algorithms, the absence of ethical and legal elements has hindered the advancement of autonomous driving toward higher levels.

Studies show that the application of automatic driving can indeed avoid 90% of traffic accidents [1], but it reflects that autonomous vehicles hardly contribute to 100% safety, and collision accidents cannot be completely avoided. As a result, Ethical decision-making dilemmas, such as the trolley problem, would occur. Without humans as direct operators, cars make driving decisions based on its system algorithm. Therefore, how to inject ethical and legal considerations into autonomous driving algorithms to solve ethical decision-making dilemmas has become an urgent and challenging problem.

Given the wide range of ethical considerations and the algorithmic practicality, our study refrains from delve into comparing the merits and demerits of various ethical values. Instead, we treat rights enshrined in constitutional principles as their prerequisites. Compared with the algorithm based purely on ethics, this structured and quantifiable method can ensure that decisions made by autonomous vehicle are based on reasonably moral considerations, and in accordance with legal norms. Additionally, it provides a more pragmatic and objective basis for decision-making, as legal norms are often clearer and more specific than ethical theories, which may be subjective and vary by culture.

In this paper, we propose a new ethical decision-making method in the self-driving system, concentrating on the application and modification of Robert Alexy's weight formula [2] and a newly developed survival rate formula [3]. This approach has been effectively used in the trade-off of constitutional rights, to solve the moral dilemma faced by autonomous vehicle. Our main contributions can be summarized as follows:

1) The integration of Rawls's Maximin Principle and the developed survival rate formula: We have enhanced the survival rate formula by incorporating more parameters in it. Rawls' concept is utilized to prioritize the protection of the most vulnerable life to the greatest extent.
2) The innovative application of Alexy's weight formula: Alexy's weight formula is an important judgment basis as our ethical algorithm of autonomous driving system, providing a new perspective for resolving moral conflicts in this context.
3) We present a complete and structured decision-making framework designed for autonomous vehicle collisions, addressing the practical use of Alexy's weight formula. This framework, integrating the right to life and health, refines survival rate calculations for handling imminent collision scenarios in self-driving. It ensures that the decisions made are both ethically sound and practically feasible.

II. RELATED WORK

Studies on autonomous driving first emerged in developed countries such as the UK, the US, and Germany, and then spread worldwide. Since the invention of the "Ghost Robotics Dogs" is invented in the early 20th century in the US, studies on autonomous driving have spanned a century. In early studies, representative examples include Donald Hebb's "Hebbian learning" and Alexey Grigorevich Ivakhnenko's "deep learning" model. These studies mainly aim to alleviate collision problems. Study results have been

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established on accident management, but few of them involve ethical issues in decision-making.

With the development of self-driving technology, addressing ethical and legal concerns in autonomous driving algorithms has has emerged as a pressing topic of discussion. The hotspots mainly focus on three categories: the first is about the development strategy and legal regulations of autonomous driving technology [4]; the second is about the allocation of infringement liability for autonomous driving; the third is ethical issues related to the algorithm design of autonomous driving. Comparing their characteristics, the first two categories have become increasingly standardized with the development of autonomous driving technology, but are also limited by the level of autonomous driving application. However, ethical issues related to the design of autonomous driving algorithms have always been regarded as the Achilles heel in the domain of autonomous driving, such as trolley problems, exemplified by ongoing debates among many researchers.

Nowadays, many ethical algorithms for autonomous driving based on different ideologies have been put forward. T. Fournier, J. Gogoll and J. F. M¨uller proposed that utilitarianism is the best solution for ethical algorithms in autonomous driving [5], [6]. But it is difficult to solve the problem when the number of people injured is equal to all possible influence. C. Bartneck et al. proposed that according to deontological ethics, the ethical correctness of behavior is evaluated by its inherent characteristics, rather than its consequences [7]. Some studies rooted in ethical rules, adjust the weight of different vehicles according to the roles or obligations assigned to them [8], and add the Hippocratic Oath to the algorithm settings [9]. J. -F. Bonnefon et al. noted in his risk ethics study that "who is more at risk of sacrifice"[10], consider the vulnerability and speed of pedestrians and other vehicles, as well as the collision angle, as basic parameters in the calculation [11]. N. Reed et al. proposed that metaethics must be taken consideration into autonomous driving, including the essence of morality, the absolutism of ethical algorithms, and the acceptability of moral heteronomy. Additionally, it is necessary to consider whether geographical and cultural differences are involved in multiple moral truths [12]. Another study based on descriptive ethics, using thought experiments, such as trolley problems, as tools/methods to evaluate social reasoning and select ethical decisions suitable for different autonomous driving collision scenarios [13].

The above algorithms have their own merits and demerits, but undoubtedly they almost fall into the trap of discussing which ideology is better. Each country and region has different customs, legal systems, moral standards, etc., and everyone's understanding of ethics is also different. Utilitarianism prioritizes minimizing harm to the fewest individuals, whereas Egoism emphasizes safeguarding the personal safety of passengers. These ideologies have different origins, making it difficult to choose the best one.

It does not imply that various ethical principles cannot be applied to specific driving scenarios, but rather requires the establishment of corresponding trade-off standards or specific application scenarios before comparing and applying various algorithms. It is an effective way to promote the quantification of ethical principles in algorithms. In addition to comparing the advantages and disadvantages of various algorithms, there have been studies attempting to establish a pre-program to balance the strengths and weaknesses of algorithms and its specific applicable scenarios, among which the more mature application is Robert Alexy's weight formula [2]. Therefore, based on the advantages of Alexy's weight formula, this paper modifies its limitations, and combines other algorithm setting tools to develop a new autonomous driving ethical algorithm that is both applicable and flexible to different scenarios.

III. PROBLEM FORMULATION

The ethical algorithm for autonomous driving developed in this study takes ethical and legal elements into consideration. It mainly consists of an improved formula for survival rate and an optimized version of Alexy's weight formula.

A. The Formula for Survival Rate

When facing inevitable collisions in autonomous driving, it is more operational for algorithmic decision-making to consider survival rate, which meets the purpose of risk prevention. Our survival rate formula is derived from Rawls' Maximin Principle, aiming to protect the rights and interests of the most vulnerable objects in collision scenarios.

In previous discussions on ethical algorithms for self-driving, the most discussed ones are respectively based on the principle of "minimizing the overall harm" from Bentham's utilitarianism and the Maximin Principle from Rawls' theory of justice. The former is in accordance with the maximum happiness and the minimum pain for the largest number of people in the community, i.e., listing various factors to measure the amount of pain, and then estimating the overall amount of pain caused to different objects by these factors [14]. The latter is based on the estimation of the survival rate of each subject in a collision, and selects the option that maximizes the interests of the subject with the lowest survival rate, thereby maximizing the minimum value [3].

Our study is based on Rawls' Maximin Principle to calculate the survival rate. We do not intend to prove that this algorithm is the best among all algorithms, but Rawls' Maximin Principle is sensitive to the minimum benefit and tends to choose the decision-making solution that maximizes the minimum benefit [15]. It doesn't advocate sacrificing the few for the benefit of the majority. Instead, it views enhancing everyone's survival rate as a higher purpose. This approach helps prevent the irreparable damage caused by the dogmatism of the "minimizing overall harm" principle, making it more aligned with "Pareto optimal." By combining the calculation of survival rate with the Alexy's principles, it not only ensures the logical consistency of the algorithm, but also meets the requirements of the algorithm's applicability and flexible adaptation to different scenarios.

Scholars have previously applied this principle to specific ethical algorithms. For example, as seen in Derek Leben's research, it constructs a utility function based on three parameters: actions taken by autonomous driving, individuals affected by actions, and individual's benefits under actions, and thereby calculating the individuals' "survival rate" [16]. This study improves the original survival rate formula after comprehensively comparing multiple algorithms, and re-establishes four parameters as variables for calculating survival rates. We will further introduce the four parameters in the following algorithm construction.

B. The Formula of Alexy's Weight

The ideological foundation of Alexy's weight formula derives from decisions of the German Constitutional Court. Cases applying Alexy's weight formula often adjust constitutional rights between private parties [17]. Due to the development of autonomous driving technology, the solution to the "Trolley Problem" has become increasingly realistic and urgent. Scholars have sorted out and compared ethical theories that are expected to be applied to the ethical decision-making of autonomous driving, such as deontology, utilitarianism, contractualism, and risk ethics [18]. However, no matter which principle is selected and which model is constructed according to the corresponding principle, it needs to be analyzed from the perspective of computational measurement, and the algorithm needs to be discussed in the context of the Constitution.Thus, the application of Alexy's weight formula in self-driving has a suitable context: in the algorithmic design of autonomous driving decision-making, instead of being restricted to the comparison and selection of algorithmic ethics, it is better to balance rights and interests of main vehicle and perdestrians (or other vehicles) after the survival rate is relatively clear.

In the application of algorithmic decision-making for autonomous driving, Alexy's weight formula is based on the pursuit of "Pareto optimality", to make at least one subject's situation better without making any subject's situation worse [19]. Pareto optimality considers the interests of weaker parties, making it preferable for values like safety and health, where careful discussion is crucial. It aims to avoid choosing "Kaldor-Hicks Efficiency," which could result in irreversible consequences, such as beneficiaries being unable to compensate victims for their losses. However, provided Alexy's weight formula is to be incorporated into the autonomous driving ethical algorithm, it is a need to resolve the appilication issue of Alexy's weight formula in algorithm decision-making of autonomous driving.

1) 1.Resolve the lack of specific scenarios and contradictions of value neutrality by strictly limiting the scope of the life value: Alexy's weight formula does not presuppose a specific comparison of the value originated from constitutional principles, but the results of the formula output imply specific algorithmic decisions that will directly affect the driving direction. In 2017, a report, Ethics Commission Automated and Connected Driving, was published by the Federal Ministry of Transport and Infrastructure of Germany. It put forward that "in hazardous situations that prove to be unavoidable, despite all technological precautions being taken, the protection of human life enjoys top priority in a balancing of legally protected interests" and "in the event of unavoidable accident situations, any distinction based on personal features (age, gender, physical or mental constitution) is strictly prohibited"[20]. These two ethical rules clearly state "the supreme priority of human life" and "prohibitions that weigh and balance the right to life with other values based on objective factors. Thus, in the algorithm of autonomous vehicles, the life loss of the collision is noticed most.

Therefore, based on the superiority of the right to life over other constitutional rights, the object of measurement by using Alexy's weight formula is not a simple distinction towards the value of life, health, and property, but rather strictly limits the scope of the life value, i.e., the trade-off of the constitutional right to life and health, including conflicts between the right to life of different individuals, the right to life and the right to health, and the right to health of different individuals.

2) Resolve the uncertainty of assignment criteria by determining safety thresholds.: According to the application of Alexy's weight formula, the value of the equation is bigger than 1, indicating the degree of realization of the protected constitutional rights is less than the degree of the damaged constitutional rights, and it fails to pass the judicial review threshold; when the value is equal to 1, the judge or legislator has discretion. Only if the value is smaller than 1, the weight of safeguarding a right is greater than the weight of infringing another right [17]. When using Alexy's weight formula, the above two constitutional rights should not be arbitrarily placed up and down the equation for trade-off, to avoid leading the equation results in opposite results because of swapping principles' upper and lower positions.

Before using Alexy's weight formula, a predefined safety threshold is established to differentiate between the survival rates associated with the rights to life and health. This threshold determines the severity of damage to a specific right. If the damage value falls below the threshold, it may result in the subject's death; if it exceeds the threshold, while damage may occur, it will not be fatal. This allows for distinguishing whether the affected right is the right to life or the right to bodily integrity. If the ratio exceeds 1, the numerator represents the compromised right to life, while the denominator represents the protected right to health. Conversely, if the ratio is less than 1, the numerator signifies the compromised right to health, and the denominator represents the protected right to life. If the ratio equals 1, both parties are affected equally. The decision outcome can be determined by calculating the overall loss. Only by balancing rights and interests based on these criteria can the degree of rights protection and infringement be effectively compared.

IV. Our Proposed Algorithm

In order to address the inevitable collision problem in autonomous driving, this study aims to propose a new ethical decision-making algorithm based on Alexy's weight formula. This algorithm is intended to assist autonomous vehicles in imminent collision scenarios by making decisions according to quantitative values derived from mathematical formulas. As Alexy's weight formula may not offer deterministic analysis for specific scenarios, this section selects the rights to life and health as the comparison elements for collision scenarios in autonomous driving.

This algorithm is divided into three steps: First, we propose an improved formula for survival rate, utilize it to calculate the survival rate of each party under different decision-making scenarios, and then select the lowest survival rate among the two parties based on the Rawls' algorithm; Second, infringement upon a certain right is judged based on the preset safety threshold used to differentiate between the consequences, either infringing the right to life or to health. If the survival rate is lower than this threshold value, the right to life is infringed, otherwise, the right to health is infringed; finally, Alexy's weight formula is employed to balance the rights infringed and protected in the collision scenario, so as to obtain the optimal decision.

A. Survival Rate

Rawlsian algorithm for autonomous vehicles introduces the difference principle and the Maximin principle in the application of autonomous vehicles facing the ethical dilemma. The Maximin algorithm makes driving decisions based on the survival rate of each party in a collision. Based on Rawls' algorithm and the necessary parameter research [21] from the Interval Type-2 Fuzzy Best–Worst Method, a new formula for survival rate is designed. This formula incorporates the actors affecting survival rates more comprehensively in quantitatively balancing the right to life and to health.

In order to obtain the survival rate accurately, 4 parameters and their weight that need to be considered are defined. However, this survival formula can also be flexibly modified according to the needs, we just list four of important parameters for reference:

1) Speed: A direct relationship exists between the vehicle speed and pedestrian survival rates in a collision. In studies of pedestrian-vehicle collisions, it has been found that high-speed collisions significantly increase the severity of pedestrian injuries [22]. In the study of Brian C. Tefft, specific values that can be referenced are given. When the speed is 24.1 mph, the average risk of death is 10%; when the impact speed is 40.6 mph, the risk of death reaches 50%; when the impact speed is 54.6 mph, the risk of death can be as high as 90% [23]. Thus, the survival rate of the pedestrian is set as V_1 when the speed reaches a certain value. The greater the speed is, the lower the survival rate is. The weight of speed's influence on the final survival rate of the collision is set as W_1.
2) Impact point: A strong relationship exists between the impact point, also known as the place of the impact, and the pedestrian's survival rate in the collision. The impact point in this paper refers to the specific place where the vehicle collides with a pedestrian or car. This point directly affects the contact area and degree of damage under the collision. Therefore, the survival rate of the impact point somewhere on the pedestrian is set as V_2. The closer the impact point is to the core part of the hit object (pedestrian or car), such as the pedestrian's head or the front of the vehicle, the larger the impact area or the greater the damage cause, the lower the survival rate is [24]. The weight of impact point' influence on the final survival rate of the collision is set as W_2.
3) Age: The impact on pedestrians' survival rates is related to the age. Compared to young adults, children and the old are more vulnerable to injury because their behavior is more erratic, their reaction times are longer, and their physical characteristics such as bones and muscles are more fragile and susceptible. Therefore, the survival rate when a certain age group is impacted is set as V_3, and the weight of the age's influence on the final survival rate of the collision is set as W_3.
4) Protector: Whether pedestrians wear protective equipment, such as helmets and reflective clothing, would affect their survival rate in a collision. For example, if a pedestrian wears a helmet, the risk of head injury can be reduced by up to 74%, effectively improving survival rate [25]. Compared with cars, people walking, riding bicycles or riding motorcycles are more likely to die. According to the 2000 China Automobile Collision and Safety Data, the above three types of deaths accounted for 61.6% of all deaths [26]. Thus, the survival rate of pedestrian with or without protection is set as V_4. The more comprehensive the body is protected, the higher the survival rate is. The weight of the protector's influence on the final survival rate of the collision is set as W_4.

Certainly, if there are additional or different factors to consider (n factors), our survival formula still applies.

To obtain a reasonable survival rate, the parameter weight is set as the sum of these parameters' weights as a percentage of the total weight should be 1. The equation is expressed as follows:

$$\sum_{i=1}^{n} W_i = 1 \tag{1}$$

The formula to calculate the survival rate is expressed as follows:

$$\text{Rate} = \sum_{i=1}^{n} W_i \times V_i \tag{2}$$

The formula could output the survival rate of each party with full consideration.Rawls' Maximin Principle is used to find the minimum in the each party's survival rates as their representative survival rates respectively, and then the safety threshold value preset in advance would be compared to the representative survival rates. If the representative survival rate is smaller than the threshold, this party has a greater risk to die, i.e., the constitutional right that is infringed is the right to life. If the survival rate is bigger than or equal to the threshold, the risk of losing life is small, and it is more likely to cause physical damage, i.e., the constitutional right that is infringed is the right to health.

B. Alexey's weight formula

Alexey's weight formula has been used to explore the balancing of constitutional principles. It has made remarkable achievements in solving moral ethics and legal justice. Therefore, it is introduced into the ethical algorithms construction of autonomous driving as the dominant theoretical framework in the inevitable vehicle collisions. Mathematical formula is applied to express the law of balance of Alexey's weight formula. Within a principle-oriented constitutional rights framework, when a conflict of rights arises between two parties, the action x chosen by the autonomous vehicle, so the W_x represents the weight of either the infringed or protected right.

Therefore, if there are two actions to choose from: a and b, the weight ratio between W_a and W_b is as follows:

$$W_{(a,b)} = \frac{W_a}{W_b} \tag{3}$$

Since Alexey's weight formula does not enumerate specific balancing principles and either determine whether they are numerators or denominators, it is assumed that if action a protected the right to life that would be infringed , and action b protected the right to health but would cause death, based on the priority to protect the right to life, $W_{(a,b)} > 1$, indicating in the collision, the autonomous vehicle should choose action b; if action a protected the right to health but would cause someone's death, and action b protected the right to life but would injure someone, $W_{(a,b)} < 1$, indicating in this collision, the autonomous vehicle should choose action a.

However, the weight of life right is likely to be equal to the weight of health right, i.e., $W_{(a,b)} = 1$.This problem could be solved by calculating an total loss. In a collision, the final total loss could be get through multiplying final survival rate by the number of lives involved. This relation can be expressed as a mathematical formula when an action "x" is chosen as follows:

$$\text{Total Loss}_x = \text{Number of Lives} \times (1 - Rate_x) \tag{4}$$

This formula reflects the loss that each involved life contributes to the final outcome in a collision, taking into account the interaction of the number of lives involved and the survival rate. This formula is used to quantitatively evaluate the overall influence of the collision, taking into account the number of casualties and the survival rate, so that the total loss becomes the basis for making decisions when Alexy's weight ratio is 1.

C. Example

To better understand the algorithm design of this paper, based on the case mentioned in A Rawlsian algorithm for autonomous vehicles and inevitable collisions faced by the autonomous vehicles, the following context is designed [15]:

On a road of a city, an autonomous vehicle with two passengers — a young driver and a child, is traveling at the legal speed limit. Suddenly, an elderly cleaner emerges from the landscape to the left of the vehicle. At this moment, the vehicle is unable to stop using its brakes. Meanwhile, a motorcycle also traveling lawfully and with two young men wearing helmets, driving alongside the vehicle on the right .

Thus, the autonomous vehicle faces an inevitable collision scenario and need to quickly choose between two actions: action a is to move forward while turning on the brake, causing a collision between the cleaner and the car; action b is to make a sharp turn and hit the motorcycle on the right.

When action a occurs, through calculation, when decelerating and going straight, the passengers in the car will suffer minor injuries due to the car's protective measures. But the cleaner will suffer greater damage compared to the passengers in the car, because the cleaner do not have any protection, the impact area will be much larger, but the cleaner is a old person. Based on the rough estimation of the survival rate formula, we assume their survival rates are as follows:

$$Rate_a = [0.7, 0.3] \tag{5}$$

When action b occurs, although the passengers on the motorcycle are wearing helmets and they are agile young men, due to the change of impact point, the impact area becomes larger. Thus, the passengers in the autonomous vehicle suffer more damage than action a. We assume their survival rates are as follows:

$$Rate_b = [0.6, 0.5] \tag{6}$$

Based on Rawls' Maximin Principle, the lowest survival rate is selected for comparison as follows:

$$Rate_a = 0.3 \quad ; \quad Rate_b = 0.5 \tag{7}$$

Assuming that the safety threshold is 0.5, it can be determined that action a infringes the right to life, and action b infringes the right to health.

Taking these two rights into Alexy's weight formula to comparison as follows:

$$W_{(a,b)} = \frac{W_a}{W_b} > 1 \tag{8}$$

Thus, the decision can be made that the autonomous vehicle should choose action b.

However, in a similar scenario, if we assume that the two passengers on the motorcycle are elderly and not wearing helmets, this will directly affect their survival rates if action "b" is chosen. Advanced age and no protection measures will further lower their survival rates, and lead to the total loss of two passengers is greater. At this time, the survival rates of the passengers on the vehicle and on the motorcycle are changed as follows:

$$Rate_b = [0.5, 0.4] \tag{9}$$

The lowest survival rate is still selected for comparison as follows:

$$Rate_a = 0.3 \quad ; \quad Rate_b = 0.4 \tag{10}$$

$Rate_a$ and $Rate_b$ are both smaller than 0.5, which means action a and action b both infringe the right to life, i.e., we have the following:

$$W_{(a,b)} = \frac{W_a}{W_b} = 1 \tag{11}$$

Hence, it will lead be impossible to make an effective decision. Accordingly, the total loss will be further calculated as follows:

$$\begin{aligned} \text{Total Loss}_a &= 1 \times (1 - 0.3) + 2 \times (1 - 0.7) = 1.3 \\ \text{Total Loss}_b &= 2 \times (1 - 0.5) + 2 \times (1 - 0.4) = 2.2 \end{aligned} \tag{12}$$

The total loss of choosing action b is greater than the total loss of choosing action a, so a decision is made: The autonomous vehicle should choose action a.

V. Conclusion

This paper is the first to incorporate Alexey's weight formula into the design of ethical algorithms for autonomous driving. This innovative combination avoids subjective comparisons of ethics superiority. Instead, it integrates the right to life from objective constitutional principles into the formula and utilizes survival rate as the sole basis for judging whether rights are infringed, thereby establishing a clear and interpretable decision-making algorithm for vehicle collisions.

This innovative algorithm design bridges the gap between legal theory and technology, enhancing the operability and practical application of the algorithm. It provides a structured and law-centered framework for solving the moral dilemma faced by autonomous vehicles.

As a future step, the algorithm shall be refined through practical applications in different legal and ethical contexts, and further upgraded in vehicle simulation environments, to realize the effectiveness and practicality of the algorithm.

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