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Decision Making via Game Theory for Autonomous Vehicles in Static Game of Complete Information

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1 INTRODUCTION

Game theory is a mathematical framework for modeling and analyzing strategic interactions between rational decision-makers. In recent years, game theory has been applied to various fields, including economics, political science, and computer science. One of the most promising applications of game theory is in the field of autonomous vehicles, where it can be used to model and analyze the interactions between these vehicles and other road users.

Autonomous vehicles are expected to play an increasingly important role in transportation in the coming years. These vehicles are equipped with advanced sensors and decision-making capabilities, allowing them to navigate complex traffic environments and make real-time decisions. However, the safe operation of autonomous vehicles also poses significant challenges, as these vehicles must be able to safely and efficiently interact with other road users.

Safety is a critical concern in the design and operation of autonomous vehicles, as accidents involving these vehicles can have serious consequences for passengers, other road users, and society as a whole. This paper aims to address this concern by using game theory to model and analyze the strategic interactions between autonomous vehicles and other road users. By using static game theory, we can identify potential safety risks and design control strategies to mitigate them. We will present case studies and simulations illustrating how static game theory can improve safety outcomes in autonomous vehicles. The study in this paper will contribute to the ongoing efforts to ensure the safe deployment of autonomous vehicles on public roads and will be a valuable resource for researchers and practitioners working in the field of autonomous vehicles, game theory and related areas.

Game theory offers a powerful tool for addressing these challenges, as it provides a mathematical framework for modeling and analyzing the strategic interactions between autonomous vehicles and other road users. In particular, static game theory, which is the focus of this paper, is well-suited to the study of autonomous vehicles, as it allows for modeling interactions between rational agents in a simplified, well-defined environment.

This paper will present a detailed study of static game theory in the context of autonomous vehicles. We will provide an overview of static game theory's key concepts and methods. We will then apply these concepts and methods to studying autonomous vehicles. Our goal is to provide an in-depth understanding of the potential benefits and limitations of using static game theory in the design and control of autonomous vehicles.

We will also explore the implications of our findings for future research in this area. The paper will include several case studies, examples, and simulations to illustrate the use of static game theory in autonomous vehicles. Our study will contribute to the ongoing efforts to ensure autonomous vehicles' safe and efficient deployment on public roads.

2 BACKGROUND

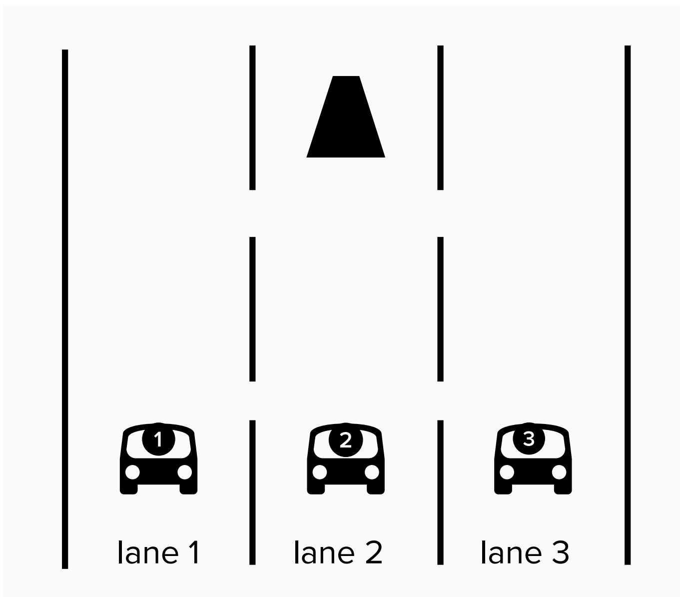

Figure 1: Representation of the game

Highways are an important part of transportation infrastructure, and the safe and efficient operation of vehicles on these roads is essential for the smooth functioning of society. With the increasing deployment of autonomous vehicles, it is becoming increasingly important to understand how they will interact with each other and human-driven vehicles on the highway.

One of the most critical challenges facing autonomous vehicles is navigating safely in complex traffic environments, mainly when obstacles are present on the road. This paper focuses on a specific scenario involving a three-lane highway, where in each lane, there is an autonomous vehicle and an obstacle present initially in the middle lane. The paper's objective is to study the behavior of autonomous vehicles in this scenario and how they react to obstacles being moved to the right and left lanes.

This scenario is particularly challenging because it requires autonomous vehicles to make decisions that consider the actions of other vehicles on the road. Game theory provides a powerful tool for modeling and analyzing these interactions. This paper will use static game theory to study the behavior of autonomous vehicles in this scenario. By using static game theory, we can identify potential safety risks and design control strategies to mitigate them.

Overall, this paper aims to provide a comprehensive and in-depth study of the use of static game theory in the context of autonomous vehicles navigating in a 3-lane highway with obstacles. It will be a valuable resource for researchers and practitioners working in the field of autonomous vehicles, game theory, and highway transportation.

3 STATIC GAME OF COMPLETE INFORMATION

Here we describe a scenario where three autonomous vehicles (AV1, AV2, and AV3) are driving on a three-lane road. An obstacle, referred to as a "Big Giant Turtle," appears in front of one of the vehicles (AV2). The situation is being looked at as a static game, with each vehicle having the choice to swerve left, swerve right, or remain in the same lane. The game's outcome will be based on the combination of actions chosen by all the vehicles, with each car trying to maximize its payoff. The obstacle is considered a typical scenario that is critical for safety.

The obstacle in the scenario will remain stationary during the game, and autonomous vehicles (AV1, AV2, and AV3) can move left, right, or stay in their current lane. The game's outcome will be determined by the actions chosen by all the AVs, with the goal for each car being to maximize its payoff. It is stated that colliding with another car is considered worse than hitting an obstacle and that going off the road is less severe than hitting something but more severe than continuing on an empty road. It is considered that if two cars swerve toward each other, they crash before hitting the obstacle(if any).

The payoffs for the different outcomes in the game are if two cars crash, the payoff is c; if a car hits the obstacle, the payoff is o; if a car goes off the road, the payoff is f; and if a car stays on the road as intended, the payoff is k. The payoffs are ranked in the order of k being the best outcome, followed by f, o, and c being the worst outcome. It is mentioned that the cost of staying on the road is considered to be 0, which makes the other outcomes negatively valued. The game's structure is summarized in tables 1,2 and 3.

This game can be considered a specific example of the "Chicken Game" where players aim to achieve the least costly outcome but through a self-centered approach. This results in identifying the most likely outcomes as the Nash equilibria (NEs), of which this game has four. The game has three NEs in pure strategies, that is, (SL, SL, R), (R, R, R), and (R, SR, SR), and also one in mixed strategies. In the mixed strategies, the probability of AVs choosing "SL" is represented by "p," and the probability of AVs choosing "R" is represented by "q" which leads to a particular outcome.

		AV2		
		SL	R	SR
AV1	SL	f,k,o	f,c,c	f,c,c
	R	c,c,o	k,c,c	k,c,c
	SR	c,c,o	c,c,c	o,c,c

Table 1: AV3 Plays SL.

		AV2		
		SL	R	SR
AV1	SL	f,k,k	f,o,k	f,c,c
	R	c,c,k	k,o,k	k,c,c
	SR	c,c,k	c,c,k	o,c,c

Table 2: AV3 Plays R.

$$p = \frac{f-c}{o-c}$$

$$q = \frac{fo - fc + kc - kf + cc + cf + cc - co}{cc - co + ko - kc}$$

3.1 DRUNK DRIVER

In this section, we will change the AV2 with a drunk driver to make the game more engaging. The layout of the game has been altered and is now presented in tables 4, 5, and 6. The difference is that AV2, the drunk driver, cannot drive straight. As a result of this modification, the number of pure strategies Nash equilibrium (NE) is reduced to two, and the strategic combination of (R,R,R) is no longer considered a NE. In the conclusion, we will discuss it more.

4 Conclusions

In summary, this paper uses static game theory to study the behavior of autonomous vehicles in a three-lane highway scenario where an obstacle is present in the middle lane. The scenario is modeled as a static game, with each vehicle having the choice to swerve left, swerve right, or remain in the same lane, and the outcome of the game is based on the combination of actions chosen by all the vehicles, with each car trying to maximize its payoff. The payoffs for the different outcomes in the game are ranked, with staying on the road being the best outcome, followed by going off the road, hitting the obstacle, and colliding with another car being the worst outcome. The paper aims to provide a comprehensive and

		AV2		
		SL	R	SR
AV1	SL	f,k,f	f,o,f	f,k,f
	R	c,c,f	k,o,f	k,k,f
	SR	c,c,f	c,c,f	o,k,f

Table 3: AV3 Plays SR.

		V2	
		SL	SR
AV1	SL	f,k,o	f,c,c
	R	c,c,o	k,c,c
	SR	c,c,o	o,c,c

TABLE 4: AV3 Plays SL.

		V2	
		SL	SR
AV1	SL	f,k,k	f,c,c
	R	c,c,k	k,c,c
	SR	c,c,k	o,c,c

TABLE 5: AV3 Plays R.

in-depth study of the use of static game theory in the context of autonomous vehicles navigating in a 3-lane highway with obstacles, which will be a valuable resource for researchers and practitioners working in the field of autonomous vehicles, game theory, and highway transportation. Indeed, in addition to the scenario described in the paper involving obstacles on a three-lane highway and autonomous vehicles, the issue of drunk driving could also be studied in the context of game theory. For example, one could model the interaction between an autonomous vehicle and a human-operated vehicle driven by a drunk driver. The autonomous vehicle, in this case, would have the choice to react in specific ways to the actions of the drunk driver, such as avoiding the vehicle or slowing down, while the drunk driver would have the choice to make decisions that could potentially put themselves and others at risk. The game's outcome would depend on the combination of actions chosen by both the autonomous vehicle and the drunk driver, with each goal being to minimize the risk of an accident. This could add another layer of complexity to the study and open up new research areas on how autonomous vehicles can effectively navigate and respond to dangerous situations caused by human drivers.

5 FUTURE POSSIBLE WORKS

In addition to the current study, future research could explore the use of Bayesian games to model and analyze the behavior of autonomous vehicles in scenarios involving obstacles and drunk drivers. Bayesian games are a type of game theory that incorporates uncertainty and incomplete information. In the context of autonomous vehicles, this could be used to model the uncertainty in the actions of other drivers on the road, including drunk drivers.

In a Bayesian game, each player has a set of possible actions and a set of possible types (or states of the world). The payoffs of the game depend not only on the actions chosen by the players but also on the types of players. The types of players can be uncertain, and each player has a prior belief about the types of the other players. In the case of autonomous vehicles and drunk drivers, the types of drivers could be defined as "sober" or "drunk," and the autonomous vehicle would have to make decisions based on its belief about the type of the other driver.

		V2	
		SL	SR
AV1	SL	f,k,f	f,k,f
	R	c,c,f	k,k,f
	SR	c,c,f	o,k,f

TABLE 6: AV3 Plays SR.

By using Bayesian games, researchers could study how autonomous vehicles make decisions in the presence of uncertain and incomplete information and design control strategies that consider the uncertainty in the actions of other drivers. This could provide a more realistic and accurate model of the interactions between autonomous vehicles and human-operated vehicles on the road and help to identify potential risks and develop solutions to mitigate them.

Overall, using Bayesian games to study autonomous vehicles in real-world scenarios involving obstacles and drunk drivers could be a promising area of future research, providing new insights and strategies for making autonomous vehicles safer and more effective on the roads.