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Research and Analysis on Policy Governance Based on Traffic Congestion in Beijing

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Abstract: This paper proposes three-game models to improve Beijing's traffic environment through the analysis method of game theory. First, the author examines the impact of improving drivers' moral character on alleviating traffic congestion. Second, this paper focus on the role of improving the public transportation environment in reducing road stress. Finally, this research examines the possibility of mitigating traffic congestion through a reward-punishment system. Comprehensive analysis of the results of these three game models, this paper conclude that a single policy of license restriction and traffic restriction is not enough to solve the traffic congestion problem in Beijing, and multiple policy measures need to be considered comprehensively. However, these policy measures also face some challenges and limitations, including time and education investment, people's travel needs and transportation network layout, and the design and implementation of the reward and punishment system. Therefore, future research and policy development need to further explore these issues and find more comprehensive and feasible policy solutions. Finally, this article recommends that the Beijing Municipal Government comprehensively consider the results of different game models and formulate comprehensive policy measures based on the actual situation, including improving road transportation facilities, encouraging green travel methods, and promoting intelligent transportation systems. Through these efforts, it is expected to improve Beijing's traffic environment, enhance citizens' travel experience, and achieve the goal of sustainable urban transportation.

Keywords: Game theory, urban traffic, countermeasures, traffic congestion

1. Introduction

As the capital of China and a densely populated city, Beijing faces serious traffic congestion problems. The proliferation of vehicles and the surging travel demand in cities far surpass the capacity of road infrastructure to accommodate them. Improving the level of road traffic management has been widely recognized as a viable solution to alleviate urban traffic issues. As of September 2022, Beijing had a total of 7.08 million registered motor vehicles. Despite the implementation of measures like traffic restrictions, these administrative efforts, which initially displayed some effectiveness, have gradually lost their potency in the face of the relentless growth in the absolute number of motor vehicles. To cope with this challenge, the Beijing Municipal Government implemented the policy of restricted traffic and restricted traffic. The Beijing restricted traffic policy refers to a traffic management measure adopted by the Beijing Municipal Government to alleviate urban traffic congestion. This

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policy restricts private cars from entering urban areas within a specific period by rotating restrictions based on the odd and even numbers of license plate numbers and specific dates [1]. Since the 2008 Olympic Games, Beijing's traffic restriction policy has become an important part of the city's traffic management. The implementation of the policy of limiting numbers and driving has had a wide-ranging impact on residents and citizens. On the one hand, this policy restricts the driving of private cars within a specific period, which brings certain inconveniences to personal travel. On the other hand, by reducing the number of vehicles, the number and traffic restriction policy can help alleviate road congestion, improve the traffic environment, and improve the city's traffic efficiency and sustainable development level. However, Beijing's policy of restricting numbers and driving traffic also faces some challenges and controversies. Some believe the policy restricts personal freedom of travel and may lead to more people buying second cars to circumvent travel restrictions. In addition, policy implementation and management also need to consider the needs and interests of different groups to ensure fairness and effectiveness. Therefore, it is difficult to fundamentally solve traffic congestion by relying on this policy alone. Therefore, this study aims to use the analytical framework of game theory to explore other possible policies to improve the traffic environment based on the traffic congestion situation in Beijing.

2. Literature review

With the rapid development of urbanization, the increase in urban population and the surge in private car ownership have led to an increasingly serious problem of urban road congestion, which has become an important obstacle to the healthy and sustainable development of cities. To solve the problem of traffic congestion, city managers have adopted several governance policies.

By analyzing the document "Comparison of Incentive and Punitive Traffic Congestion Governance Policies - Based on Dynamic Evolutionary Game Model and Simulation Analysis" which studies traffic congestion governance policies [2]. It is clear that the author analyzed the impact of different governance measures on urban traffic congestion by establishing an evolutionary game model of travelers' transportation mode choice behavior and explained the results of these impacts.

This evolutionary model divides travelers into two categories, one tends to choose public transportation and the other tends to choose private cars. This article analyzes the costs and benefits of travelers choosing different travel modes under different traffic congestion control policies and derives a benefit matrix as the policies change. At the same time, the evolutionary stability strategies of the two types of travelers under different policies were studied. To analyze the evolution process and results more intuitively, the author conducted simulations and found that punitive measures are more effective than incentive measures in alleviating traffic congestion, with faster effects and longer-lasting effects.

By analyzing this article, it is distinct that Beijing's existing transportation system has some shortcomings, which may lead to long-term inefficiency. Therefore, the design of the system needs to be further improved. For example, traffic management can be improved by drawing on methods such as reward and punishment systems. Therefore, this article aims to introduce other methods that can improve Beijing's traffic situation through game analysis.

Through game theory research methods, individuals can gain an in-depth understanding of the impact of different governance measures on traffic congestion problems and provide new ideas for improving Beijing's traffic conditions. Future research can further explore and evaluate the feasibility and effectiveness of these methods to formulate more effective traffic governance policies and achieve sustainable development of Beijing's transportation system.

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3. Summarize Governance Policies through Game Models

Table 1: Game matrix under the policy of traffic restrictions based on the last digit of license plate numbers

	A		
B		Not Limited	Limited
	Not Limited	(2,2)	(3,-3)
	Limited	(-3,3)	(-3,-3)
	no limit on the tail numbers of both parities		
	Figure One		

	A		
B		Not Limited	Limited
	Not Limited	(1，1)	(2，-2)
	Limited	(-2，2)	(-2，-2)
	The tails numbers of both parties are restricted		
	Figure Two		

	A		
B		Not Limited	Limited
	Not Limited	(2,1)	(3,-2)
	Limited	(-3,2)	(-3,-2)
	Tail number of A is not limited, tail number of B is Limited		
	Figure Three		

	A		
B		Not Limited	Limited
	Not Limited	(2,2)	(3,-3)
	Limited	(-3,3)	(-3,-3)
	Tail number of A is limited, tail number of B is not limited		
	Figure Four		

By analyzing the first game matrix in table 1, both parties A and B have no limit on their tail numbers and can go on the road; It is easy to find that when both are on the road, the utility is 2 due to congestion; neither party is on the road. Being late has a utility of - 3. And when one of the two parties goes on the road and the other does not go on the road, the utility of the person who goes on the road is 3, and the utility of the person who does not go on the road is - 3. Therefore, comprehensive analysis shows that for A, when A chooses to hit the road, choosing the top lane is B's relative advantage strategy. When A chooses not to hit the road, B will still choose to hit the road. In the same way, whether B chooses to hit the road or not, A's absolute advantage strategy is Both are on the road, and the Nash equilibrium of the game is that both are on the road. Traffic congestion will occur. In the second game matrix, the tail numbers of both parties A and B are restricted at the same time and cannot go on the road; then both A and B will face fines and congestion cost-utility of 1 if they go on the road; neither A and B will go on the road, both parties will face being late but the cost-utility of saving fines will be -2; One of the two parties is on the road and the other is not. The one who is on the road has a utility of 2 due to the fine. The person who is not on the road faces being late but the utility of saving the cost of fines is -2. Therefore, for both parties A and B, no matter how the other party changes their strategies, going up the road is their dominant strategy. Then the Nash equilibrium is still the decision of both parties to go up the road, which produces a crowded result. In the same way, in the two situations of Figure 3 and Figure 4, no matter how the two sides change their strategies, the top lane is the dominant strategy, so the Nash equilibrium in both cases is a top lane.

Therefore, it can be seen from this game theory matrix that Beijing's traffic restriction system still has some problems, which may lead to long-term inefficiency. Therefore, the design of the system needs to be further improved. In the long run, traffic congestion is a fact, and the result is the same no matter how the strategy is chosen. The Nash equilibrium illustrates the long-standing problem of the shortcomings of this system [3]. Currently, to achieve the desired results, solutions to Beijing's traffic congestion problem need to comprehensively consider various factors and formulate more effective policy measures. In terms of system design, existing problems need to be solved to improve long-term efficiency. In addition, more in-depth research and understanding of residents' responses and adaptive behaviors to restrictive measures, as well as the impact of various economic behaviors on traffic congestion problems, are needed [4].

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3.1. Improving the Moral Character of Drivers

Assume that pedestrians and motor vehicles appear in the vertical direction of an unsignalized intersection at the same time, and both want to cross the road to the opposite side. Both parties believe that the shorter the time it takes them to pass the intersection, the greater the benefits will be, so there is a rush to pass.

Table 2: Benefit matrix of pedestrians and motor vehicles competing for the right of way

		Motor vehicle	
Pedestrian		Rush in traffic	Give way
	Rush in traffic	(A,A)	(B,C)
	Give way	(C,B)	(D,D)

For example, table 2 analyzes the game matrix of both parties, assuming that both parties rush to pass the intersection, and each obtains the same benefit A; when one party rushes to pass and the other party yields, the rushing party spends the shortest time passing the intersection and obtains the maximum benefit B. Although the time it takes for the courteous party to pass the intersection is shorter than the time required for both parties to rush, benefit C obtained by the courteous party is smaller than benefit A due to the psychological discomfort of the courteous party. When both parties yield, the time required to pass the intersection is between the above two methods. Between situations, the resulting benefit D is between benefits A and B because some waiting time may be wasted. Through analysis, B>D>A>C, whether for pedestrians or motor vehicles, the optimal strategy is (rush, rush). Pedestrians and motor vehicles are both rational traffic participants. Both parties pursue maximizing benefits, thus falling into a "prisoner's dilemma".

If traffic managers conduct road safety education for participants in traffic behaviors and make participants realize that being courteous to each other is traffic ethics, otherwise the harm caused by traffic accidents will cause greater losses to the participants' benefits, or the traffic managers will strictly supervise and Punish the discovered behavior of rushing, so that participants will automatically modify their benefit values, making D>B and C>A in the income matrix (courtesy, courtesy) become the only Nash equilibrium, and it is the optimal equilibrium.

In this game model, government policy support is also the most important part. The government can improve the awareness and knowledge level of traffic participants by carrying out traffic safety education activities so that they understand traffic rules and safe behaviors. At the same time, the traffic monitoring system should be strengthened, such as installing surveillance cameras and using intelligent traffic management technology, to monitor traffic violations and take necessary punitive measures promptly [5]. And citizens should also strictly implement traffic rules and systems, strengthen traffic law enforcement, and ensure that traffic rules are effectively implemented. For bad traffic behaviors, such as running red lights, speeding, etc., monitor and impose necessary penalties to strengthen traffic participants' awareness and sense of responsibility for obeying the rules. Helping citizens improve their moral awareness is also an important part. The government can improve the moral awareness of traffic participants through education and publicity, emphasizing the importance of obeying traffic rules and the responsibility for road safety. Promote mutual respect, comity, and safety awareness, and promote a civilized and harmonious traffic environment.

3.2. Improve Public Transportation Environment

Although the annual report of Beijing Transportation Development shows that Beijing's green travel proportion in 2023 will be 73.4% and the public transportation proportion will be 24.4%, more and more citizens and the government's investment focus are tilting towards public green transportation

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[6]. However, if public transportation development is not properly planned, it may become a source of traffic congestion. Too many overlapping bus routes will lead to internal congestion problems, and unreasonable route planning will increase people's travel time and may cause larger-scale traffic congestion. Each bus stop itself may also become a bottleneck for traffic congestion [7].

Assume that multiple people share a public road resource and are divided into group 1 and group 2 based on their choice of public transportation or private car. In this way, there are four strategic combinations.

Table 3: Benefit matrix of different groups taking different modes of transportation

	A		
B		BUS	CAR
	BUS	(A,A)	(B,C)
	CAR	(C,B)	(D,D)

As shown in Table3, according to the analysis of the income matrix, if both groups choose to travel by bus, each will obtain the same income A; if one group chooses a car and the other group chooses a bus, the group that takes the bus will feel uncomfortable due to the crowding in the bus. The group that chooses to travel by private car will suffer losses such as transfer and congestion time costs, and will receive a very low benefit B, while the group that chooses to travel by private car will receive excess benefit C; if both members choose to travel by private car, both will receive benefit D. At this time, both parties in the game constitute a static game with complete information.

According to the income matrix, C >A, D >B. Due to the huge time cost of traffic congestion, D is smaller than A, so C>A>D>B. When choosing a travel mode, rational people in both groups will pursue the maximization of their interests, and the (private car travel, private car travel) method becomes their dominant strategy. If the government or transportation managers adopt the favorable policy of bus priority, so that the income becomes A > C, B > D, (bus travel, bus travel) will become the new dominant strategy and the best choice for transportation participants.

Based on the analysis of this game theory model, the author intuitively see the efforts that the government can make to further alleviate traffic problems, including increasing the rationality of bus network lines; improving the effectiveness of bus roads; increasing financial investment support; building an integrated transportation and urban land use planning, etc.

Professor Pigou in the early 20th century can also be applied to this game theory matrix. According to Pigou's theory, the most direct way to solve the traffic congestion problem is to require all people who use transportation facilities and services to pay actual social Marginal costs, which include the external costs of burdens and damages they impose on society [8]. In other words, Pigou believed that traffic users should be responsible for the impact of their actions on other people and society. By imposing appropriate taxes and fees, governments can expose transport users to more accurate costs that reflect the impact of their actions on the environment, traffic flows, and other travelers. This tax can be dynamically adjusted based on peak traffic demand and congestion levels to guide people to choose alternative travel modes or reduce unnecessary travel during peak hours. This theory can give the government one more rectification method when faced with citizens choosing to travel by private cars.

4. Conclusion

Through a comprehensive analysis of Beijing's traffic congestion management strategies, this review paper believes that the Beijing municipal government should comprehensively consider the results of

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different game models and formulate a series of comprehensive policy measures based on the actual situation. These measures can include improving the construction and maintenance of road transportation facilities, encouraging the development of green travel methods, and promoting the application of intelligent transportation systems. Through these efforts, this research expected to improve Beijing's transportation environment, enhance citizens' travel experience, and achieve the goal of sustainable urban transportation. However, the implementation of these policy measures may face some challenges and limitations that require further research and policy development. Future work should explore these issues in depth and find more comprehensive and feasible policy options. Through continued efforts and innovation, Beijing can address traffic congestion and build a more livable, green and efficient urban transportation system.

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