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# The Impact of the Gradual Popularization of Autonomous Vehicles on Reversible Lane Optimization for Road Network

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**ABSTRACT:** In order to grasp the impact of the gradual popularization of autonomous vehicles on reversible lane optimization for road network, this paper first analyzes the equilibrium flow mode, which is the user equilibrium mode, the user equilibrium-system optimal hybrid mode and the system optimal mode of the road network where autonomous vehicles are gradually becoming popular. Then analyze the effect of the gradual popularization of autonomous vehicles on reversible lane optimization. And it is concluded that after the road network was optimized with reversible lanes, the total time of the road network initially showed a decreasing trend as the proportion of autonomous vehicles increased. However, when the proportion of autonomous vehicles reached a certain value, the total time of the road network no longer continued to decrease.

**KEYWORDS:** Traffic engineering, Transport planning, Reversible lane optimization, Autonomous vehicles.

## I. INTRODUCTION

The implementation of reversible lanes can well optimize the spatial and temporal allocation of road network resources to adapt to the tidal traffic flow and improve the operation efficiency of the road network, which has strong practicability and ease of operation, so it has been widely adopted by the traffic management departments at home and abroad, and has become a hot topic of research by relevant scholars.

Chen<sup>[1]</sup> based on the analysis of the traffic characteristics such as traffic flow and service level of Shuxin Road in Chengdu city, according to the relevant requirements of setting reversible lanes, the specific setting scheme suitable for the reversible lanes of tidal traffic flow is put forward, which alleviates the traffic congestion in the morning and evening rush hours of Shuxin Road to a certain extent. Yue<sup>[2]</sup> demonstrated the necessity and feasibility of implementing reversible lane optimization during the Shanghai World Expo, and studied the specific implementation plan from the aspects of scheme design and supporting measures. Finally, the implementation effect was evaluated using saturation as an indicator, and it was pointed out that reversible lane optimization can significantly reduce the traffic pressure in the direction of heavy traffic flow during the morning and evening peak periods of the World Expo passageway, thereby improving the service level of the road network. Cai<sup>[3]</sup> considered the impact of the number of lanes on the average lane capacity of road sections, and studied the reversible lane optimization method of road network while ensuring the effectiveness of the entire transportation system and then constructed a bi-level programming model for reversible lane optimization in the road network. Zhang<sup>[4]</sup> constructed a technical framework for dynamic lane reversal to increase the traffic capacity of roads during peak traffic and emergency evacuation using reversible lanes, in order to achieve rapid lane direction reversal to adapt to dynamic traffic flow changes. He proposed integer linear programming and bi-level programming models to maximize the improvement of road network capacity through reversible lane optimization. Li<sup>[5]</sup> proposed a reversible lane adjustment method suitable for urban arterial roads from off peak to peak hours to make the periodic flow direction of the reversible traffic system change more safely and smoothly. Hausknecht<sup>[6]</sup> pointed out that the reversible lane system can enhance the capacity of congested road sections, effectively alleviate traffic congestion during peak hours and emergency evacuation periods. Based on the instantaneous traffic flow recorded by traffic sensors, a dynamic adjustment method for reversible lanes was proposed, and a reversible lane optimization model was constructed with the goal of maximizing traffic volume. Wu<sup>[7]</sup> takes minimizing the total travel time and flow entropy of the system as the upper optimization objective, and the lower level is a random user assignment problem with a first in and out traveler information system. Through numerical

examples, it is demonstrated that using reversible lane optimization and advanced traveler information systems greatly reduces the total travel time of the system.

However, the above research results are all about the optimization of reversible lanes in the road network of ordinary vehicles. With the progress and implementation of science and technology such as 5G and artificial intelligence, autonomous vehicles will gradually enter the road network, affecting human travel. Considering that autonomous vehicles are constrained and influenced by various factors such as economy, technology, and law, the road network will be in a mixed state of ordinary and autonomous vehicles for a long period of time in the future<sup>[8]</sup>. However, there are currently few research results on the impact of the gradual popularization of autonomous vehicles on the reversible lane optimization of road networks. Therefore, this article considers the principles of mixed travel between ordinary vehicles and autonomous vehicles, as well as reversible lane optimization, to study this problem.

## II. EQUILIBRIUM FLOW MODE OF TRAFFIC

Assuming that ordinary vehicle users have a clear understanding of the network traffic status when making path choices, and all vehicles in the road network are ordinary vehicles, they always follow the principle of the shortest actual travel time when choosing a path. Through the game between travel demand and network supply, the final road network is the User Equilibrium Flow Mode (UE).

Assuming that autonomous vehicle users have a clear understanding of the network traffic state when making path choices, and all vehicles in the road network are autonomous vehicles, they always follow the principle of choosing the shortest path of marginal time for travel. Through cooperation between vehicles, the road network ultimately forms the system optimal mode (SO).

With the gradual popularization of autonomous driving vehicles, there are fewer and fewer ordinary vehicles in the road network, and there are more and more autonomous driving vehicles. There is a situation in the network where users follow both UE and SO criteria for travel. The game between these two types of travel users forms the UE-SO mixed traffic flow equilibrium model.

And when the proportion of autonomous vehicles  $\lambda$  reaches a certain value  $\lambda_p$ , the road network reaches the optimal state of the system, and the total travel time of the system no longer decreases. Therefore, it is not difficult to deduce:

$$T_{UE} \leq T_{UE-SO} \leq T_{SO} \quad (1)$$

Where:  $T_{UE}$  represents the total time of the system when the road network in user equilibrium mode,  $T_{UE-SO}$  represents the total time when the road network in user equilibrium-system optimal hybrid mode,  $T_{SO}$  represents the total time when the road network in the system optimal mode.

If and only if the actual time shortest path is the marginal time shortest path, there are:

$$T_{UE} = T_{UE-SO} = T_{SO} \quad (2)$$

When the shortest path in actual time is not the shortest path in marginal time, only  $\lambda \geq \lambda_p$ , there are:

$$T_{UE-SO} = T_{SO} \quad (3)$$

## III. ANALYSIS OF THE IMPACT OF AUTONOMOUS VEHICLE PROPORTION ON REVERSIBLE LANE OPTIMIZATION

Note the road section set of the entire reversible road network as  $a$ , assuming that any road section  $a$  has the reverse section  $\bar{a}$ , and the two-way road section  $\ddot{a}$  composed of sections  $a$  and  $\bar{a}$ , the flow of the road section  $a$  is  $\hat{x}_a$ , the autonomous vehicle flow of the road section  $a$  is  $\tilde{x}_a$ , the normal vehicle flow of the road section  $a$  is  $\bar{x}_a$ ,  $s_a$  indicating the number of lanes of the road section  $a$ ,  $c_a$  indicating the traffic capacity of a single lane in the road section  $a$ . The free travel time of the section  $a$  is  $t_a^0$ , the travel time of each reversible lane is  $t_a(\hat{x}_a, s_a)$ , and the functional form adopts BPR formula:

$$t_a(\hat{x}_a, s_a) = t_a^0 \left[ 1 + 0.15 \left( \frac{\hat{x}_a}{c_a \cdot s_a} \right)^4 \right], \quad a \in A \quad (4)$$

$$\hat{x}_a = \bar{x}_a + \tilde{x}_a, \quad a \in A \quad (5)$$

Reversible lane optimization refers to the adjustment of road resources in the direction of light traffic flow to the use of traffic in the direction of heavy traffic flow based on the bi-directional unbalanced flow of the road section, thereby increasing the traffic capacity of the road in the direction of heavy traffic flow, reducing road congestion, and reducing road travel time. From formulas (4) and (5), it can be seen that after reversible lane optimization, the travel time of the road section depends on the total flow of the road section, that is, the proportion of autonomous vehicles  $\lambda$  in the total flow of the road section does not affect the travel time of the road section. So for the entire road network, the total system time after reversible lane optimization depends on the distribution of road network traffic, which is also affected by the proportion of autonomous vehicles  $\lambda$ .

When the proportion of autonomous vehicles  $\lambda = 0$ , the optimized road network with reversible lanes is in UE mode, and the total time of the road network system is  $T'$ ; As the proportion of autonomous vehicles  $\lambda$  increases, the optimized road network with reversible lanes adopts a UE-SO hybrid mode, and the total time of the road network shows a decreasing trend; When the proportion of autonomous vehicles increases to  $\lambda = \lambda_p$ , the optimized road network with reversible lanes is in SO mode, and the total time of the road network system is  $\bar{T}$ ; As the proportion of autonomous driving vehicles  $\lambda$  further increases to  $\lambda = 1$ , the optimized road network with reversible lanes is in SO mode, and the total time of the road network system no longer continues to decrease. The total time of the road network system is  $\tilde{T}$ . From this, it can be seen that with the popularization of autonomous vehicles, the trend of the total time of the road network system  $T$  after reversible lane optimization is shown in the Fig.1.

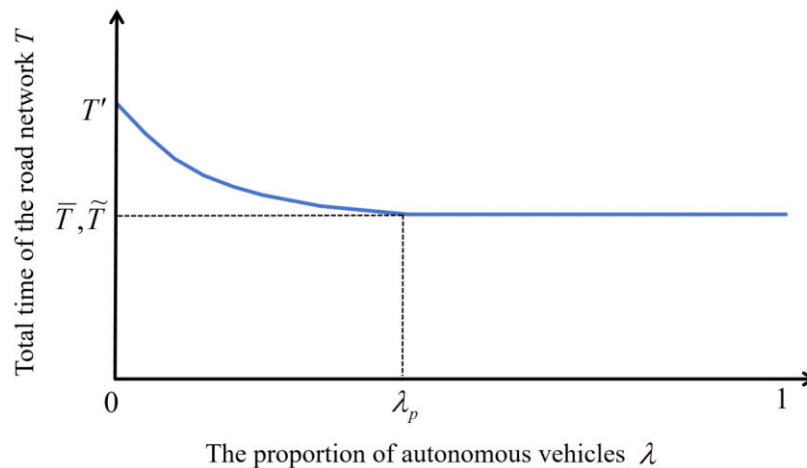


Fig.1 The Trend of the Total Time of the Road Network System with the Popularization of Autonomous Vehicles

#### IV. CONCLUSION

With the gradual popularization of autonomous vehicles, it has a certain impact on the distribution of traffic flow in the road network, which in turn affects the optimization effect of reversible lanes in the road network. After reversible lane optimization of the road network, as the proportion of autonomous vehicles  $\lambda$  increases, the total time of the road network shows a downward trend. However, when the proportion of autonomous vehicles  $\lambda$  reaches a certain value, the total time of the road network no longer continues to decrease, indicating that the road network system has reached the optimal state under reversible lane optimization and cannot be further optimized by increasing the proportion of autonomous vehicles.



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