Research on Guiding Technology for Ecological and Safe Driving of Vehicles

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Abstract. Based on the vehicle-road coordination technology, the decision-making model of vehicle entering signalized intersection and the optimization model of eco-driving speed guidance are studied. Using vehicle speed guidance technology to provide drivers with guidance information can effectively reduce vehicle fuel consumption and enhance vehicle safety. This paper establishes an engine fuel consumption model based on power demand and an optimization model of vehicle speed guidance based on exponential function. Then conduct simulation tests on the energy-prioritized vehicle speed guidance optimization model designed in this paper and obtain the speed optimization curve under different traffic conditions. The test results show that after the vehicle is guided by the vehicle speed guiding model, its driving speed and acceleration are relatively smooth, which can effectively reduce the fuel consumption. When the initial speed is the same, the vehicle passes through the intersection just when the signal lamp changes. At this time, the fuel consumption of the vehicle is lower than the other guidance modes that meet the model and when the vehicle is properly accelerated, the fuel consumption rate has little effect. But at the time of deceleration, the fuel consumption rate suddenly changes and the fuel consumption increases rapidly.

1. Introduction

Based on the increasingly serious energy problems, research on intersection speed guidance technology that prioritizes energy consumption on the basis of vehicle-road coordination has gradually become a new development trend. The main point of ecological driving is to control the speed of the vehicle in a "peaceful" way, and to reduce the fuel consumption and exhaust emissions of the vehicle by improving the driving skills to achieve the purpose of ecological energy saving.

Y. Saboohi et al. developed an optimal driving strategy model to avoid excessive fuel consumption in severe traffic conditions. The model uses vehicle speed and gear ratio as control variables and the objective function is to minimize the fuel consumption in a given route, which can provide energy-saving vehicle speed guidance services [1]. Hesham A. Rakha et al. calculated the transit time to determine whether the vehicle need to be accelerated or decelerated. For the situation that requires acceleration and deceleration, they studied the determination of the acceleration and deceleration time and adopted a linear calculation method to enumerate the vehicle speed curve. The curve with the smallest fuel consumption value is used as a signalized intersection vehicle speed guidance function [2].

Foreign researchers have studied the speed guidance of signalized intersections and ecological driving earlier. But there are still some problems with the current speed guidance of ecological driving at intersections. When optimizing fuel consumption, the safety constraints are not complete. The speed guidance may cause the vehicle to exceed the road speed limit and the minimum speed of the vehicle.
is not considered. According to actual needs, the driver is not easy to manipulate. There are fewer domestic related researches than foreign countries and the research focuses on simulation tests. The vehicle-road collaboration technology is not well applied to the speed guidance of intersections.

Based on the above background, this paper researches on vehicle ecological and safe driving guidance technology to build energy-efficient vehicle speed optimization guidance model based on vehicle-road collaboration and provides drivers with energy-saving vehicle speed guidance services to reduce parking waiting time and fuel consumption and the purpose of vehicle delays.

2. Methodology
This chapter establishes a vehicle-road coordination technology-based signalized intersection vehicle speed guidance optimization model.

2.1. Speed guide scene
Vehicle-road collaboration technology can realize the collection and processing of traffic information, and establish efficient information sharing between people, vehicles and roads.

There are many factors that affect the traffic environment. The speed guidance method studied in this article is for a single vehicle passing through a two-phase signalized intersection and so the vehicle speed guidance model is established on the basis of the following basic assumptions:
- The study area is a single intersection and the influence of adjacent intersections is not considered.
- Disregard the interference of surrounding vehicles, pedestrians and non-motor vehicles.
- The guiding vehicle is a straight-going vehicle and the traffic conflicts with vehicles in other directions after entering the signalized intersection are not considered.
- The vehicle has adjusted its lane and kept going straight before entering the speed guidance area.

2.2. Engine fuel consumption model based on power demand
The research of engine fuel consumption model is the research foundation of vehicle speed guidance model. The fuel consumption model can be used to evaluate the fuel consumption performance of different vehicle speed curves and obtain the best speed curve. The fuel consumption model used in this paper is the power-based micro fuel consumption model VT-CPFM [8].

\[
P(t) = \frac{(R(t) + ma(t)(1.04 + 0.0025\xi(t)^2))}{3600\eta_d}v(t)
\]

\(P(t)\) is the power applied by the vehicle transmission system at time \(t\); \(\xi\) represents the transmission ratio of the vehicle at time \(t\) and \(\eta_d\) represents the efficiency of the vehicle driveline.

The typical value of the vehicle coefficient is as follows:

\[
R(t) = \frac{\rho}{25.92}C_D C_h A_f v(t)^2 + 9.8066m \frac{C_r}{1000}(c_1 v(t) + c_2) + 9.8066m G(t)
\]

\(\rho\) represents the air density at sea level at a temperature of 15°C; \(C_D\) represents the drag coefficient of the vehicle; \(C_h\) is the height correction factor and is calculated as 1-0.085H; \(A_f\) is the frontal area of the vehicle; \(C_r\), \(c_1\) and \(c_2\) are the rolling resistance parameters that change according to the road surface type, road condition and vehicle tire type.

The VT-CPFM-1 model based on power demand is as follows. \(\alpha_0\), \(\alpha_1\) and \(\alpha_2\) are vehicle-specific model constants calibrated for each vehicle.

\[
FC(t) = \begin{cases} 
\alpha_0 + \alpha_1 P(t) + \alpha_2 P(t)^2 & \forall P(t) \geq 0 \\
\alpha_0 & \forall P(t) < 0 
\end{cases}
\]

In the VT-CPFM-1 model, at any instant \(t\), the power applied by the vehicle is:

\[
P(t) = \frac{(R(t) + 1.04ma(t))}{3600\eta_d}v(t)
\]
The power applied by the vehicle in the VT-CPF M-1 model is a function of vehicle speed and acceleration. This model is suitable for implementation in microscopic traffic simulation software but cannot be used to develop predictive environmentally friendly shifting strategies, because the change in engine speed caused by vehicle gear changes cannot be reflected in fuel consumption estimates.

2.3. Traffic decision model

According to the principle of energy-saving driving, vehicles should avoid stopping and waiting when passing signalized intersections and minimize the energy loss caused by unnecessary acceleration and deceleration operations [3-4]. If the time when the vehicle is at the point $S_q$ is the origin of time, in order to make the vehicle reach the signalized intersection with a green light, the time when the vehicle reaches the point $S_o$ should be:

$$ t_p = \begin{cases} 
[0, t_r) or [t_g, t_r], & \text{if phase } = G \\
[t_g, t_r), & \text{if phase } = R 
\end{cases} $$

(5)

$t_r$ refers to the moment when the signal light just turns to red; $t_g$ refers to the moment when the signal light just turns to green and $t_{r1}$ refers to the time when the signal light turns to red for the second time.

The vehicle traffic decision model analysis at signalized intersections is as follows.

In the case of "phase=G", there will be two green light windows. If the following conditions are met, the vehicle will pass at a constant speed:

$$ v_0 t_c > d_s $$

(6)

Otherwise, the traffic conditions can be divided into the following two types.

The vehicle accelerates to the road speed limit value at the maximum acceleration $a_{max}$ considering driving comfort and continues to drive at the speed limit value. The distance passed is $d$. If the following conditions are met, the vehicle can accelerate through:

$$ v_0 t_c \leq d_s $$

$$ v_{lim} t_c - \frac{1}{2} a_{max} \left( \frac{v_{lim} - v_0}{a_{max}} \right)^2 > d_s $$

(7)

After the vehicle accelerates to the road speed limit at the maximum acceleration $a_{max}$, it still cannot pass the speed guidance area in front of the signalized intersection stop line. At this time, the vehicle should stop and wait for the end of the red phase:

$$ v_{lim} - \frac{1}{2} a_{max} \left( \frac{v_{lim} - v_0}{a_{max}} \right)^2 \leq d_s $$

(8)

In the case of "phase=R", when the remaining time of the signal lamp is $t_c$ and if the following conditions are met, the vehicle will pass at a constant speed:

$$ v_0 t_c < d_s $$

(9)

Otherwise, the following two situations may occur.

The vehicle decelerates at the maximum deceleration $a_{min}$. When the vehicle speed is reduced to the first gear idling speed $v_d$, keep driving at a constant speed. If satisfied

$$ v_0 t_c \geq d_s $$

$$ v_d t_c + \frac{1}{2} a_{min} \left( \frac{v_d - v_0}{a_{min}} \right)^2 < d_s $$

(10)

The result of the decision-making for vehicle traffic at this moment is to slow down and pass the signalized intersection.

When the vehicle decelerates to the minimum idle speed at the maximum deceleration $a_{min}$ that considers driving comfort and safety and continues to drive to the intersection stop line, the signal light is still red. If the following conditions are met, the vehicle will stop and wait.

$$ v_d t_c + \frac{1}{2} a_{min} \left( \frac{v_d - v_0}{a_{min}} \right)^2 \geq d_s $$

(11)
2.4. An optimal model of vehicle speed guidance based on exponential function

The predefined optimal acceleration or deceleration curve model (time-varying function of speed) based on the exponential function is as follows:

\[
\begin{align*}
v &= \begin{cases} 
    v_0 + (v_0 - v_s) \cdot e^{(-s_1 \cdot t)} & t \leq t_s \\
    v_0 - (v_0 - v_s) \cdot e^{(-s_2 \cdot (t - t_s))} & t > t_s
    \end{cases}
\end{align*}
\]

\[
⑫
\]

\(v_s\) represents the vehicle speed when the vehicle passes through the signalized intersection stop line; \(t_s\) represents the time elapsed when the vehicle travels from the starting position of the speed guidance area to the signalized intersection stop line; \(s_1\) and \(s_2\) are parameters that determine the shape of the vehicle speed guide curve in exponential form. Whether the curve generated by this model is an acceleration curve or a deceleration curve is determined by the state of the intersection signal light.

In this model, \(v_0\), \(t_c\), \(t_s\), \(x_s\), and \(x_f\) are all known. And \(v_s\), \(s_1\), and \(s_2\) are unknown parameters. It can be seen that the problem of solving the optimal velocity curve has been transformed into a problem of solving the parameters \(v_s\), \(s_1\), and \(s_2\).

The constraints that this model needs to meet are time and distance constraints and acceleration constraints. The maximum acceleration that the driver can accept is \(2.5 \text{ m/s}^2\) \(⑩\). The maximum acceleration value selected during the establishment of the vehicle speed optimization model is \(a_{\text{max}} = 2.0 \text{ m/s}^2\). The maximum deceleration value is \(a_{\text{min}} = 2.5 \text{ m/s}^2\) \(⑪\). This model takes the fuel consumption model as the objective function.

3. Simulation test and analysis

3.1. Speed up boot simulation

The simulation test scenario settings are shown in Table 1.

| Parameter | Value |
|-----------|-------|
| \(v_0\)   | 11(m/s) |
| \(t_c\)   | 10(s) |
| \(t_s\)   | 8,9,10(s) |
| \(x_s\)   | 120(m) |
| \(x_f\)   | 250(m) |
| Signal period | G(15 s), R(15 s), Y(3 s) |

If the vehicle passes through the signalized intersection just before the end of the green light through acceleration guidance, perform simulation calculations in Matlab to obtain vehicle speed guide curves and fuel consumption during vehicle acceleration.

It can be seen from Figure 1 that after the vehicle speed guidance model guides the vehicle speed, the vehicle can change at a relatively stable speed. At the same time, the acceleration changes in a smooth and continuous curve before and after the signalized intersection. The vehicle has a sudden deceleration and sudden acceleration of acceleration. This sudden change process may have a certain impact on driving comfort and safety. From the final fuel consumption graph, it can be seen that when the vehicle is just starting to accelerate, the fuel consumption increases rapidly and the deceleration process has little effect on the change of fuel consumption[7]. It can be seen that this optimization model has a certain effect on reducing fuel consumption.
By comparing the fuel consumption curves of vehicles with different passing times, it can be found that when the vehicle has a higher acceleration, its fuel consumption is higher. The higher the initial speed of the vehicle is, the lower the fuel consumption is.

3.2. Deceleration guided simulation

| Parameter | Value                  |
|-----------|------------------------|
| $v_0$     | 11 (m/s)               |
| $t_c$     | 15 (s)                 |
| $t_s$     | 15, 16, 17 (s)         |
| $x_e$     | 120 (m)                |
| $x_f$     | 250 (m)                |
| Signal period | G (20 s), R (15 s), Y (3 s) |
If the vehicle passes through the signalized intersection by the deceleration guidance just when the red light ends and the green light turns on, carrying out the simulation calculation in Matlab can get the vehicle speed guide curve during the deceleration process as shown in Figure 1.

It can still be seen from the figure that the defect of this model is that the vehicle has a sudden acceleration after passing through a signalized intersection, which may have a certain impact on driving comfort and safety[8]. From the fuel consumption curve in the figure above, it can be seen that the vehicle deceleration operation has little effect on fuel consumption. However, when the vehicle accelerates rapidly at the intersection, the fuel consumption rate suddenly increases. It can be seen that acceleration has a certain effect on fuel consumption. The impact of acceleration is relatively large.

4. Conclusions
The main tasks completed in this article are as follows:
A vehicle traffic decision model is established at signalized intersections. Finally, the corresponding simulation test and analysis on the established vehicle speed change optimization model are carried out. However, during the speed guidance process, the vehicle will experience sudden changes in speed and acceleration at signalized intersections, which will affect driving comfort and driving safety. In this model, the distance from the vehicle to the intersection and the distance from the start of the vehicle guidance to the return to the initial speed are fixed values. The distance restricts the vehicle speed guidance, which in turn affects the vehicle’s guidance speed and acceleration, and easily changes the smoothness of the vehicle.

Acknowledgments
I encountered many difficulties and obstacles in the process of writing the thesis, but these problems were solved with the help of students and teachers. Here, I would like to express my most heartfelt thanks to my mentor and classmates who have helped me.

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