Research on Optimization of Vehicle Driving from the Perspective of Saving Energy

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Abstract: Optimization of vehicle driving can reduce energy consumption and carbon emission. According to analyzing the differences of time constraints, two driving situations are proposed. In this study, vehicle energy-consumption models based on energy consumption minimization are built and the soft such as MATLAB is employed to solve the models. By calculating, minimal energy-consumption value and related variable values on different driving distances or time constraints are got which contribute to guiding drivers taking energy-consumption driving behaviors.

Key words: Energy-saving and low-carbon, driving behavior, vehicle energy-consumption model, energy-consumption optimization

INTRODUCTION

In recent years, road transportation industrial has achieved rapid development in promoting the development of society and economy and also brought a series of negative side effects. The first problem is energy consumption problems. Transportation industry is one of the fastest growing industries in energy consumption. In the United State, transportation system consumes 60% of total fuel, of which 73% are consumed by road transport (Khan, 1996); while in Canada transportation system accounts for 66% and almost all are consumed by road transport. In China, transportation fuel consumption generally takes 30% and transportation energy consumption takes about 7% in total energy consumption (Zhang et al., 2003). Considering the shortage of petroleum resources, transportation system’s excessive dependence on petroleum resources would seriously affect the future economic growth. The second problem is ecological environment problems. The increase of number of vehicles inevitably causes higher emissions.

In all means of transportation, road transport emissions of greenhouse gas take 78% (Bektas and Laporte, 2011). China’s statistics also shows that in urban atmospheric pollution, locomotive tail gas pollution takes 20-50% while in Shenzhen the rate reaches as high as 70% and the specific gravity are still in growing (Gu and Zhang, 2010). Pollutants accumulation produced by urban vehicles will surpass the self-purification ability of environment and destroy the balance of urban ecological environment.

It is necessary to adopt various means to alleviate negative effects such as consumption and carbon emissions brought by road transport. Optimization on vehicle driving, having important significance on energy-saving and low-carbon to the whole road transport system, is an effective means which deserves further study. At present, research on optimization of railway train automatic driving schemes are more and focus on ATO train algorithm (Wang, 2011; Ge, 2011; Xu, 2008). Car driving optimization mainly research on driving optimization decision based on driving behaviors like car-following driving, free travel driving and lane-changing driving (Reuschel, 1950; Pipes, 1953; Ahmed et al., 1996; Almed, 1999; Wen et al., 2006). Many scholars research on vehicle driving routing problems based on energy-saving and low-carbon (Kolb and Wacker, 1995; Xiao et al., 2012; Bektas and Laporte, 2011). To achieve optimization objects of energy-saving and low-carbon, this study focuses on the decisions of variables like acceleration, speed and time under free travel diving model from different views. At first, two driving situations are proposed which one is with time constraints and the other is not, then optimization models are built and solved, finally optimization results are analyzed.

Problem analysis: The basic situation of vehicle driving is: Vehicle drive from standstill and operation process is divided into three stages. The first stage (acceleration phase) is: Speed up at the uniform acceleration of a and operation after t, speed reaches v0 - at. The second stage (uniform phase) is: Keep constant speed till t. The third phase (decelerating phase) is: Keeping speed-down, vehicle is still when time is t, and the total running distance is S. The question is: How does the vehicle drive...
that can minimize fuel consumption or carbon emissions. The relationship between operation speed and time is shown in Fig. 1. Considering that vehicle fuel consumption and carbon emissions are positively linear correlation, for simplicity, the minimization of energy consumption is the optimization target in this study.

Fuel instantaneous consumption model, invented by Bowyer (1985), are used to present fuel consumption rate of vehicles:

\[
f_i = \begin{cases} 
  s \beta \rho R \nu v + (\beta \rho M a \nu^2) & \text{for } R_i > 0 \\
  s & \text{for } R_i \leq 0 
\end{cases}
\]

In this model, \( f_i \) is fuel consumption per unit time (fuel consumption rate, the unit is mL sec\(^{-1}\)); \( R_i \) is traction (kN), the sum of air resistance and inertial force (without considering gradient force produced by slope) and \( R_i = b_i + b_2 \nu^2 - Ma \). \( S \) is fixed fuel rate at the idle speed, \( S = 0.375-0.556 \text{ mL} \text{ sec}^{-1} \). \( \beta \) is fuel consumption per specific energy, \( \beta = 0.08-0.09 \text{ mL} \text{ kJ}^{-1} \). \( \beta \) is accelerated fuel consumption per specific energy, \( \beta = 0.02-0.03 \text{ kJ} \text{ m sec}^{-2} \). \( b_i \) is rolling resistance, \( b_i = 0.1-0.7 \text{ kN} \). \( b_2 \) is rolling air resistance, \( b_2 = 0.00003-0.0015 \text{ KN(m sec}^{-2} \). \( a \) is instantaneous acceleration (m sec\(^{-2} \)), \( M \) is weight (t), \( \nu \) is velocity (m sec\(^{-1} \)).

**Vehicles in the operation of the third stage:** Vehicle speed decreases from \( v_1 = \nu_1 \) to 0 at the maximum deceleration of \( a_{max} \), then driving distance is \( \frac{(\nu_1 \nu_2)}{2a_{max}} \). \( a_{max} \) is the maximum deceleration and the general value under good road conditions is 4-8 m sec\(^{-2} \). Braking time is \( t_1 = \frac{\nu_1}{a_{max}} = \nu_1 / a_{max} \), then \( t_1 = t_2 + t_0 \).

Fuel consumption rate and fuel consumption of three phases are as follows:

\[
f_i = s \beta \rho R \nu v + (\beta \rho M a \nu^2) = s \beta (b_i + b_2 \nu^2 - Ma) v + \beta \rho M a \nu^2
\]

\[
f_i = s + \beta \rho R \nu - s + \beta (b_i + b_2 \nu^2 - Ma) v
\]

\[
f_i = s
\]

According to differences of the time constraints, two situations are divided:

- **Situation 1:** Finishing the whole driving process without time constraints
- **Situation 2:** Finishing the whole driving process with time constraints

For the two situations, optimization models are built separately and the results are analyzed and compared.

**OPTIMIZATION UNDER SITUATION 1**

**Build model:** Build the objective function on minimization of energy-consumption:

\[
\text{Min} F = \int_0^t f_i \, dt + \int_{t_1}^t f_i \, dt + \int_{t_2}^t f_i \, dt = s a_{max} + \frac{\beta b_i a_{max}^3}{4} + \frac{\beta b_2 a_{max}^3 (t_0 - t_1)}{2}
\]

**Constraint conditions s.t.:**

\[
\begin{align*}
S &= \frac{1}{2} a_{max} \nu_1^2 (t_0 - t_1) + (a_{max})^2 / 2a_{max} \\
\nu_1 &= \nu + a_{max} / t_1 \\
a &= 0 \\
0 &< t_1 \leq t_0
\end{align*}
\]

**Model solving:** The above model is nonlinear programming with constraint conditions for minimum, with the application of MATLAB toolbox to solve. Fmincon function is used to solve based on characteristics of model, \( a, t_0, t_1, t_2 \) are model variables. Parameters are set as follows:

\[
\begin{align*}
\nu_1 &= 0.45, \beta_1 = 0.085, \beta_2 = 0.025, M = 2.5, b_i = 0.4, \\
b_2 &= 0.001, a_{max} = 6
\end{align*}
\]

Table 1 is optimization results and Fig. 2 is relationship between acceleration, running time, top speed, fuel consumption value and velocity.

By analyzing, conclusions are as follows:

- Fuel consumption value \( F \), time \( t_0, t_1, t_2 \) and top speed \( \nu_{max} \) increase gradually with the increasing of driving distance \( S \), however acceleration a in acceleration phrase is on the contrary
- The equation \( t_0 \neq t_2 \) means uniform phrase is existed and constant speed running increases with the increasing of driving distance \( S \). The operation schematic diagram is shown in Fig. 3
Table 1: Calculation results of situation I

<table>
<thead>
<tr>
<th>Distance S (m)</th>
<th>Acceleration a (m sec$^{-2}$)</th>
<th>Time t₁ (sec)</th>
<th>Time t₂ (sec)</th>
<th>Time t₃ (sec)</th>
<th>Top speed $v_{max}$ (m sec$^{-1}$)</th>
<th>Minimum value of fuel consumption F (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1.1765</td>
<td>4.3673</td>
<td>21.2216</td>
<td>22.0771</td>
<td>5.137255</td>
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<td>104.7780</td>
<td>106.4557</td>
<td>10.066190</td>
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<td>151.3875</td>
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<td>181.6121</td>
<td>183.5193</td>
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<td>188.3459</td>
</tr>
</tbody>
</table>

Fig. 2(a-d): Relationship between variables and distance

Fig. 3: Operation schematic diagram of situation I
Table 2: Calculation results of situation 2

<table>
<thead>
<tr>
<th>Time $t_0$ (sec)</th>
<th>Acceleration $a$ (m/sec$^2$)</th>
<th>Time $t_1$ (sec)</th>
<th>Time $t_2$ (sec)</th>
<th>Time $t_3$ (sec)</th>
<th>Top speed $v_{top}$ (m/sec$^2$)</th>
<th>Minimum value of fuel consumption $F$ (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>33.8499</td>
<td>2.5967</td>
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<td>104.7724</td>
<td>106.4500</td>
<td>10.0652</td>
<td>102.8148</td>
</tr>
</tbody>
</table>

The relationship between energy consumption and time is shown in Fig. 4.

By analyzing, conclusions are as follows:

- When $t_0 < 106.45$ sec, the minimum fuel consumption is 102.8 mL.
- When $t_0 < 106.45$ sec, the smaller the $t_0$ is, the larger the fuel consumption is.
- The smaller the $t_0$ is, the more sensitive the fuel consumption is. When $t_0 \to 0$, the ful $\to \infty$.

**CONCLUSION**

The study puts forward two driving situations, optimizes each situation and calculates minimum value of fuel consumption and related variable values in different distances. Conclusions, having impact on low-carbon and energy-saving vehicles driving, are drawn by comparing and analyzing results of optimization under two situations. Means of transport like locomotive and airplane are easier to ensure automated control than vehicles. Therefore, low-carbon and energy-saving driving of those transports needs further study.

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