Research on Optimization of Vehicle Driving Based on Energy-saving and Low-carbon

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Abstract: Optimization of vehicle driving can reduce energy consumption and carbon emission. According to differences of vehicle braking mode, two driving situations are proposed. In this context, 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 are got, which contribute to guiding drivers taking energy-consumption driving behaviors. Finally conclusions are drawn by comparing and analyzing results of optimization under two situations.

Keywords: Driving behavior, energy-consumption optimization, energy-saving and low-carbon, vehicle energy-consumption model

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 inevitable causes higher emissions. According to statistics, greenhouse gas emissions of American’s transportation system increased from 24.9% in 1990 to 27.3% in 2005. And 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 to 50%, while in Shenzhen the rate reaches as high as 70% and the specific gravity are still in growing (Gui 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; Ahmed, 1999; Wen et al., 2006). Many scholars research on vehicle driving routing problems based on energy-saving and low-carbon (Alexander and Manfred, 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, then optimization models are built and solved, finally optimization results are analyzed.

PROBLEM ANALYSIS

The basis 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 $t_a$ speed reaches $v_a = at_a$. The second stage
Fig. 1: The relationship between running speed and the time of vehicles

stage (uniform phase) is: keep constant speed till \( t_b \).  
The third phase (decelerating phase) is: keeping speed-down, vehicle is still when time is \( t_c \) 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 et al. (1985), are used to present fuel consumption rate of vehicles:

\[
f_i = \begin{cases} 
  s + \beta_1 R_i v + \left( \beta_2 M a^2 \right) v & \text{for } R_i > 0 \\
  s & \text{for } R_i \leq 0 
\end{cases}
\]

In this model, 
\( f_i \) = Fuel consumption per unit time (fuel consumption rate, the unit is mL/s)  
\( R_i \) = Traction (KN), the sum of air resistance and inertial force (without considering gradient force produced by slope) 
\( R_i = b_1 + b_2 v^2 + Ma \)  
\( S \) = Fixed fuel rate at the idle speed, \( s = 0.375 \sim 0.556 \) mL/s  
\( \beta_1 \) = Fuel consumption per specific energy, \( \beta_1 = 0.08 \sim 0.09 \) mL/KJ 
\( \beta_2 \) = Accelerated fuel consumption per specific energy, \( \beta_2 = 0.02 \sim 0.03 \) KJ/m/s\(^2\) 
\( b_1 \) = Rolling resistance, \( b_1 = 0.1 \sim 0.7 \) KN 
\( b_2 \) = Rolling air resistance, \( b_2 = 0.00003 \sim 0.0015 \) KN/(m/s\(^2\))  
\( a \) = Instantaneous acceleration (m/s\(^2\))  
\( M \) = Weight (t) 
\( v \) = Velocity (m/s)

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

\[
f_1 = s + \beta_1 R_i v + \left( \beta_2 M a^2 v \right) 
\]

\[
f_2 = s + \beta_1 R_i v = s + \beta_1 \left( b_1 + b_2 v^2 \right) v 
\]

\[
f_3 = s 
\]

According to differences of vehicle braking mode, two situations are divided:

**Situation I (no braking):** In the third phrase, parking relies on resistance not braking.

**Situation II (braking):** In the third phrase, parking relies on braking.

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

**BUILD MODEL**

**Optimization model under situation I:** Parking in the operation of third stage relies on resistance not braking.

Build the objective function on minimization of energy-consumption:

\[
Min F = \int_0^{t_a} f_1 dt + \int_{t_a}^{t_b} f_2 dt + \int_{t_b}^{t_c} f_3 dt = 
\]

\[
st_c + \frac{\beta_1 b_2 a^3}{4} t_a^4 + \left( \beta_1 b_2 a + \beta_2 M a^2 + \beta_3 M a^3 \right) t_a^2 
\]

\[
+ \left( \beta_1 b_2 a t_a + \beta_1 b_2 a^3 t_a \right) (t_c - t_a) 
\]

Constraint conditions:

\[
\begin{align*}
S & = \frac{1}{2} a t_a^2 + at_a (t_b - t_a) + \frac{1}{2} at_a (t_c - t_b) \\
\alpha & > 0 \\
0 & < t_a \leq t_b \leq t_c
\end{align*}
\]

**Optimization model under situation II:** Vehicles in the operation of the third stage: vehicle speed decreases from \( v_{ta} = at_a \) to 0 at the maximum deceleration of \( a_{max} \), then driving distance is \( \left( at_a \right)^2/2a_{max} \). \( a_{max} \) is the maximum deceleration and the general value under good road conditions is 4~8 m/s\(^2\). Braking time is \( T_c = \frac{v}{a_{max}} = at_a/a_{max} \), than \( t_c = t_b + t_e \).
Objective function is the same as situation I and changes of constraint conditions are as follows:
\[
\begin{align*}
S &= \frac{1}{2} a t_a^2 + at_a(t_b - t_a) + \left(\frac{a}{a_{\text{max}}} - 1\right) t_a^2 \\
t_a &= t_b + \frac{t_c}{a_{\text{max}}} \\
a &> 0 \\
0 &< t_a \leq t_b
\end{align*}
\]

RESULTS

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, ta, tb, tc are model variables. Parameters are set as follows:

\[
S = 0.45, \beta_1 = 0.085, \beta_2 = 0.025, M = 2.5, b_1 = 0.4, \quad b_2 = 0.001, \quad a_{\text{max}} = 6
\]

Optimization results of model I: Table 1 shows optimization results for different driving distances and Fig. 2 are relationship between acceleration, running time, top speed, fuel consumption value and velocity. By analyzing, conclusions are as follows:

- Fuel consumption value F, acceleration a in acceleration phrase, time ta reaching top speed and

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<th>Distance S (m)</th>
<th>Acceleration a (m/s²)</th>
<th>Time ta (s)</th>
<th>Time tb (s)</th>
<th>Time tc (s)</th>
<th>Top speed vmax (m/s)</th>
<th>Min. value of fuel consumption F (mL)</th>
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Table 2: Calculation results of model II

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<th>Acceleration a (m/s²)</th>
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<th>Time t_b (s)</th>
<th>Time t_c (s)</th>
<th>Top speed v_max (m/s)</th>
<th>Min. value of fuel consumption F (mL)</th>
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Fig. 4: Relationship between variables and distance

Fig. 5: Operation schematic diagram of situation II

- Top speed $v_{max}$ increase gradually, with increasing of driving distance $S$, however end time is on the contrary.
- The equation $t_a = t_b$ means no uniform phrase. The operation schematic diagram is shown in Fig. 3.

Optimization results of model II: Table 2 is optimization results and Fig. 4 is relationship between acceleration, running time, top speed, fuel consumption value and velocity.

By analyzing, conclusions are as follows:

- Fuel consumption value $F$, time $t_a$, $t_b$, $t_c$ and top speed $v_{max}$ increase gradually with the increasing of driving distance $S$; however acceleration $a$ in acceleration phrase is on the contrary.
- The equation $t_b \neq t_a$ 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. 5.

Comparative analysis of model I and II: The main difference of two situations exists in the third phrase,
namely braking relying on resistance or parking brake. After optimization, a, t_a, t_s, t_c and minimum value of fuel consumption F under different driving distances of two situations are concluded. By comparing and analyzing. It can conclude:

- Through optimization, with increasing of distance, a is on the increase and t_c decreases in situation I, and a and t_c in situation II is opposed to situation I. Trend of other characteristics (t_s, v_max, and F) keep in consistence.

- From the point of total driving time, when the distance is short, total driving time of situation I is far greater than the value of situation II, however if distance is bigger than a certain value (in this model, the certain value is about 1300 m), result is on the contrary. Therefore, if time is a sensitive factor, situation II is used when driving distance is shorter, situation I is adopted in longer driving distance.

- In shorter distance, minimal value of fuel consumption of situation I is bigger than that of situation II; when distance is bigger than a certain value (in this model, the certain value is about 600 m); value of situation II is bigger than that of situation I. Therefore, to save fuel, situation II is suitable for shorter driving distance and situation I applies to longer driving distance.

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 of vehicles driving, are drawn by comparing and analyzing results of optimization under two situations. Means of transport like locomotive and plane are easier to ensure automated control than vehicles. Therefore, low-carbon and energy-saving driving of those transports needs further study.

REFERENCES


