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Research Article

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 $v_{ta} = at_a$. The second stage

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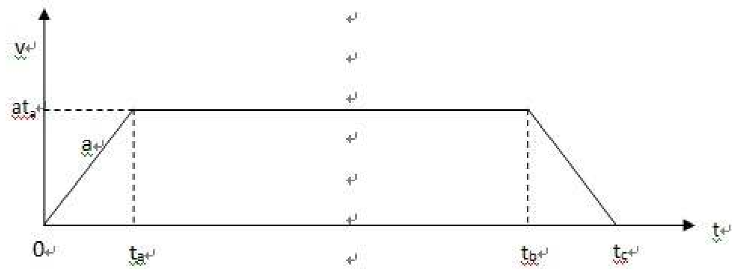

Fig. 1: The relationship between running speed and the time of vehicles

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:

$$f_t = \begin{cases} s + \beta_1 R_t v + \left(\beta_2 M a^2 v\right) & for R_t > 0 \\ s & for R_t \le 0 \end{cases}$$

In this model,

- f_t = Fuel consumption per unit time (fuel consumption rate, the unit is mL/s)
- R_t = Traction (KN), the sum of air resistance and inertial force (without considering gradient force produced by slope)
- R_t = $b_1 + b_2v^2 + Ma$
- S = Fixed fuel rate at the idle speed, s = 0.375 ~ 0.556 mL/s
- β_1 = Fuel consumption per specific energy, β_1 = 0.08 ~ 0.09 mL/KJ
- β_2 = Accelerated fuel consumption per specific energy, β_2 = 0.02 ~ 0.03 KJm/s^2
- b_1 = Rolling resistance, b_1 = 0.1 ~ 0.7 KN
- b_2 = Rolling air resistance, b_2 = 0.00003 ~ 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:

$$f_1 = s + \beta_1 R_t v + \left(\beta_2 M a^2 v\right)$$

$$= s + \beta_1\left(b_1 + b_2 v^2 + Ma\right)v + \beta_2 M a^2 v$$

$$f_2 = s + \beta_1 R_t v = s + \beta_1\left(b_1 + b_2 v^2\right)v$$

$$f_3 = s$$

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:

$$MinF = \int_0^{t_a} f_1\,dt + \int_{t_a}^{t_b} f_2\,dt + \int_{t_b}^{t_c} f_3\,dt =$$

$$st_c + \frac{\beta_1 b_2 a^3}{4} t_a^4 + \frac{\left(\beta_1 b_1 a + \beta_1 M a^2 + \beta_2 M a^3\right)}{2} t_a^2$$

$$+ \left(\beta_1 b_1 a t_a + \beta_1 b_2 a^3 t_a^3\right)\left(t_b - t_a\right)$$

Constraint conditions:

$$\text{s.t.} \begin{cases} S = \frac{1}{2} a t_a^2 + a t_a\left(t_b - t_a\right) + \frac{1}{2} a t_a\left(t_c - t_b\right) \\ a > 0 \\ 0 < t_a \le t_b \le t \end{cases}$$

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 $(at_a)^2/2a_{max}$. a_{max} is the maximum deceleration and the general value under good road conditions is 4~8 m/s^2. Braking time is $T_e = v/a_{max} = at_a/a_{max}$, than $t_c = t_b + t_e$.

Objective function is the same as situation I and changes of constraint conditions are as follows:

s.t.

$$\begin{cases} S = \frac{1}{2}at_a^2 + at_a(t_b - t_a) + (at_a)^2 / 2a_{\max} \\ t_c = t_b + at_a / a_{\max} \\ a > 0 \\ 0 < t_a \le t_b \end{cases}$$

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, t_a, t_b, t_c are model variables. Parameters are set as follows:

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

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 t_a reaching top speed and

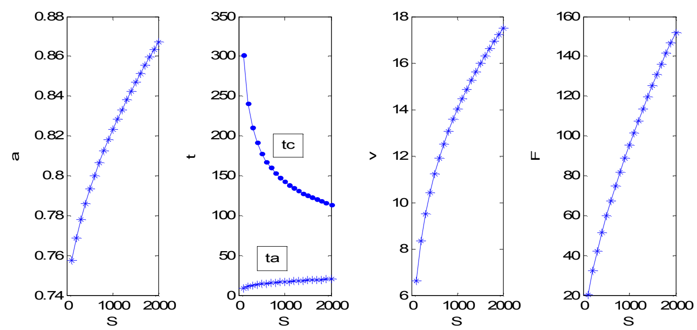

Fig. 2: Relationship between variables and distance

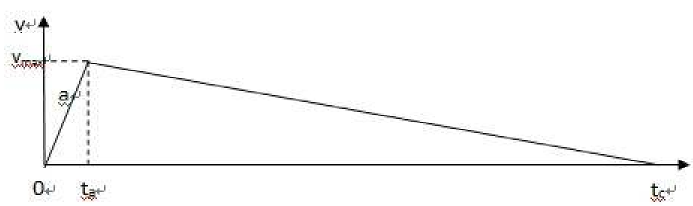

Fig. 3: Operation schematic diagram of situation I

Table 1: Results of model 1

Distance S (m)	Acceleration a (m/s^2)	Time t_a (s)	Time t_b (s)	Time t_c (s)	Top speed v_{max} (m/s)	Min. value of fuel consumption F (mL)
100	0.7574	8.7456	8.7456	301.9469	6.6237	20.3263
200	0.7688	10.8233	10.8233	240.3685	8.3206	32.3157
300	0.7780	12.2140	12.2140	210.4757	9.5023	42.3988
400	0.7862	13.2757	13.2757	191.6310	10.4367	51.4190
500	0.7935	14.1424	14.1424	178.2227	11.2219	59.7257
600	0.8001	14.8802	14.8802	167.9953	11.9051	67.5063
700	0.8066	15.5138	15.5138	159.8341	12.5130	74.8763
800	0.8124	16.0793	16.0793	153.1011	13.0633	81.9128
900	0.8180	16.5856	16.5856	147.4184	13.5668	88.6710
1000	0.8234	17.0447	17.0447	142.5081	14.0343	95.1915
1100	0.8284	17.4663	17.4663	138.2230	14.4694	101.5059
1200	0.8332	17.8557	17.8557	134.4297	14.8777	107.6389
1300	0.8381	18.2114	18.2114	131.0387	15.2627	113.6106
1400	0.8426	18.5461	18.5461	127.9835	15.6270	119.4374
1500	0.8471	18.8571	18.8571	125.2027	15.9741	125.1330
1600	0.8513	19.1528	19.1528	122.6606	16.3051	130.7091
1700	0.8555	19.4286	19.4286	120.3242	16.6218	136.1755
1800	0.8595	19.6930	19.6930	118.1636	16.9257	141.5409
1900	0.8634	19.9413	19.9413	116.1604	17.2176	146.8126
2000	0.8673	20.1769	20.1769	114.2924	17.4990	151.9973

Table 2: Calculation results of model II

Distance S (m)	Acceleration a (m/s^2)	Time t_a (s)	Time t_b (s)	Time t_c (s)	Top speed v_{max} (m/s)	Min. value of fuel consumption F (mL)
100	1.1763	4.3673	21.2216	22.07781	5.137255	17.0484
200	1.0428	6.1887	33.5479	34.62350	6.453576	28.4630
300	0.9731	7.5231	44.1289	45.34902	7.320729	38.7892
400	0.9275	8.5924	53.8238	55.15204	7.969451	48.5670
500	0.8943	9.4864	62.9735	64.38745	8.483688	58.0096
600	0.8686	10.2534	71.7533	73.23765	8.906103	67.2260
700	0.8480	10.9228	80.2667	81.81046	9.262534	76.2799
800	0.8309	11.5146	88.5798	90.17438	9.567481	85.2123
900	0.8164	12.0431	96.7377	98.37636	9.831987	94.0508
1000	0.8027	12.5403	104.7780	106.45570	10.066100	102.8148
1100	0.7932	12.9496	112.7075	114.41940	10.271620	111.5188
1200	0.7837	13.3422	120.5607	122.30340	10.456280	120.1734
1300	0.7753	13.7017	128.3454	130.11590	10.622930	128.7870
1400	0.7677	14.0322	136.0728	137.86820	10.772520	137.3661
1500	0.7609	14.3373	143.7512	145.56940	10.909250	145.9158
1600	0.7548	14.6198	151.3875	153.22670	11.035030	154.4402
1700	0.7492	14.8824	158.9874	160.84570	11.149890	162.9429
1800	0.7440	15.1269	166.5557	168.43140	11.254410	171.4265
1900	0.7393	15.3554	174.0961	175.98810	11.352250	179.8935
2000	0.7350	15.5693	181.6121	183.51930	11.443440	188.3459

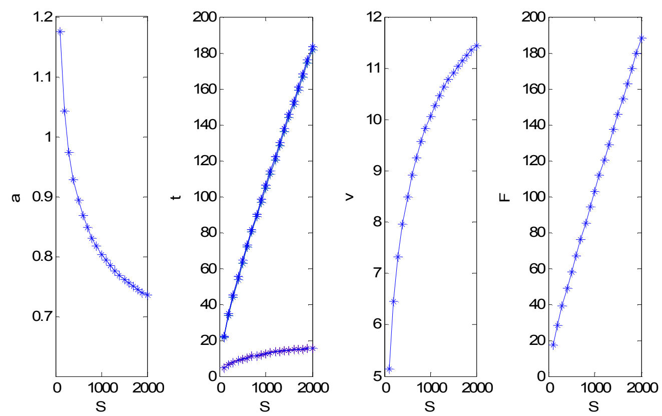

Fig. 4: Relationship between variables and distance

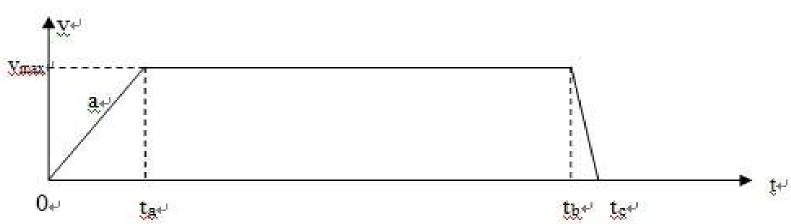

Fig. 5: Operation schematic diagram of situation II

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_b, 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_a, 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.

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