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The UFC Model of Analysis the Effect of Road Gradient on Car Fuel Consumption

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Abstract
In order to reduce automobile fuel consumption in the process of uphill, based on the Vehicle dynamics and the principle of power balance, we construct two models. One is unit fuel consumption model(UFC),

$$UFC = UFC_{io} + \alpha_3 \times RPM + \alpha_1 \times HP_{et} + \alpha_2 \times RPM \times HP_{et}.$$

Keywords: *fuel consumption . road grade .the best speed . ant colony algorithm*

1. Problem description

Cars have become one of the most important transportation in the world, and play an necessary role in our daily life. With the increase of cars, the demand for fuel will increase continually .but we have to realize the shortage of oil resources in our country, which will have a bad effect on the development of cars, so resolving the relationship between the demand for oil and the development of the automobile industry has become extremely important, what is worth mentioning is that we can relieve the pressure of the oil shortage by means of saving oil resource or find a new energy taking the place of it.

2. Problem analysis

For the moment ，there are three main models about road conditions and fuel consumption，which are multiple regression fuel consumption model, bench test fuel consumption model, theoretical fuel consumption model ,respectively. And these models have their own advantages and disadvantages.
As for, multiple regression fuel consumption model, whose data come from large-scale field experiment in the same place , that is ,even though the data is reliable, it can’t be applied to the other place.
And the bench test fuel consumption model ,based on the consumption power speed,was used to do many experiments. So if you want to apply this model to the actual you need to have special equipment to obtain the experimental data.
The last one,theoretical fuel consumption model , based on the principle of conservation of energy, using Newton's laws established through mechanical analysis and the experimental calibration, is the one we build in the article.using this method to establish model can overcome the shortcoming of the above two models, therefore,it is considered to be a good modeling method.
Fuel consumption model theory is the study of road gradient and vehicle speed, determine the different speed case, the car's fuel consumption. For different sections of data collection, can make simulation diagram, simulation fitting equation of fuel consumption under different conditions, to establish the objective function, with the speed of the ant colony algorithm to calculate the minimum fuel consumption.

3. Model Assumptions

(1)The data we obtained is relatively accurate
(2)Car drivers’ drive level has no effect on the experimental data
(3)ignore the impact that was brought by gasoline weight.

4. Symbols

HP ，power；KW
RPM ，engine speed；r/min
UFC ，Unit fuel consumption；ml/s
HP_{it} ，internal power；KW
HP_{et} ，external power；KW

Annotation：some symbols that don’t mention in this part will be explained when we use them.

5. build the model of unit fuel consumption model(UFC):

The fuel consumption model is build on the basis of the theory that the engine fuel consumption is a function of the engine power and speed. And the engine power can be divided into two kinds--internal power,and external power. Internal power is used to overcome the internal friction of the engine, ancillary facilities (fan, motor, etc.) and the external power is used to overcome the road resistance, air resistance, etc. According to this reason,engine fuel consumption can be divided into engine internal power needed to fuel consumption and external power needed to fuel consumption.

The above theory can be used under type said:

$$UFC = f(HP, RPM) \quad (5\text{-}1)$$

$$HP = HP_{it} + HP_{et} \quad (5\text{-}2)$$

$$UFC = UFC_{it} + UFC_{et} \quad (5\text{-}3)$$

In fuel consumption theory,we define per unit output power consumption of fuel as α。

General studies agree that α is a function of engine speed and can be approximately expressed as linear relationship:

$$\alpha = UFC / HP = \alpha_1 + \alpha_2 \times RPM \quad (5\text{-}4)$$

According to the above formula (5-4) We can get the following formula ：

$$UFC = (\alpha_1 + \alpha_2 \times RPM) \times HP \quad (5\text{-}5)$$

Because the power can be divided into internal and external power, fuel consumption can be divided into internal and external fuel consumption. Make the formula （5-2）and formula（5-5） combined，After sorting, we come to the conclusion that:

$$UFC = (\alpha_1 + \alpha_2 \times RPM) \times HP_{it} + (\alpha_1 + \alpha_2 \times RPM) \times HP_{et} \quad (5\text{-}6)$$

Internal power is defined as a constant，by reason that Internal power value is small, and difficult to estimate. In this way, fuel consumption becomes the engine speed and power output function, it includes external and internal fuel oil consumption of two parts.

We define that : $\alpha_1 HP_{it} = UFC_{io}$, $\alpha_2 HP_{it} = \alpha_3$.

Combining with the above formulas, we can get the following formula:

$$UFC = UFC_{io} + \alpha_3 \times RPM + \alpha_1 \times HP_{et} + \alpha_2 \times RPM \times HP_{et} \quad (5\text{-}7)$$

An HP_{et} d then we get fuel consumption model using UFC as a dependent variable， ，RPM as argument, UFC_{io} as constant,and α_1 , α_2 , α_3 as parameters. And then we calibrated the constant and parameters in the formula （5-7）by using the method of multivariate statistical regression and different models of the unit fuel consumption prediction model is estalished .

It must be a mention that the formula （5-7) is on the condition that external power is greater than zero,and if the external power is less than zero the external power and engine fuel consumption without correlation, namely the engine fuel consumption is zero,This formula (5-7) can be turned into:

$$UFC = UFC_{io} + \alpha_3 \times RPM \, (HP_{et} \le 0) \quad (5\text{-}8)$$

So, in fact, for each of the cars, their predict oil consumption model consists of two parts namely type (5-7) with type (5-8), respectively corresponding to the output power is greater than zero and the output power is less than zero.

To finish the step of calibrating the parameters,we should deal with the date we have ,and determine the engine power, rotational speed and the unit fuel consumption.After which we can have a complete formula.

5.1The calculation of engine power

When the car is on the straight sections, there are mainly four kinds of forces acting on the car, the rolling resistance, air resistance, the slope of resistance and inertial resistance.and when the car is on the sections containing curvature ,car will also be affected by curvature resistance.

When the car running at steady speed, inertial resistance is zero, the force acting on the car only rolling resistance, air resistance, gradient and curvature resistance, resistance.

In order to simplify the model,we think the road does not contain the curvature ,and according to power balance theory that car engine output power is always equal the mechanical transmission loss power and total power consumed by a motion resistance, the engine power output can be estimated by type:

$$HP_{et} = (RRF + ARF + GF) \times v / 1000 / \eta_t \quad (5\text{-}9)$$

The rolling resistance, air resistance, resistance are the function of road roughness, slope speed and wind speed, road slope respectively.

Specific interpretation and analysis of all kinds of resistance just as follows:

5.1.1 Rolling resistance RRF

$$RRF = G \times f \quad (5\text{-}10)$$

When the wheel rolling, due to the deformation between wheels and the ground and energy loss produced by the interaction between the two known as rolling resistance.Plastic deformation of the road and tire elastic hysteresis can produce rolling resistance.

When the car run on the hard pavement, the deformation is the main factor of the tire, the tire radial, tangential and lateral deformation.The coefficient of rolling resistance f can be measured through experiment,and It is subject to the type of pavement, smoothness, rigidity, tires, tire pressure and speed.

The following are some coefficient of rolling resistances in different occasions （chart-1）。

Chart -1 coefficient of rolling resistance

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The kind of road surface	coefficient of rolling resistance
Good asphalt or concrete pavement	0.010~0.018
The general asphalt or concrete pavement	0.018~0.020
Gravel road	0.020~0.025
Good gravel road	0.025~0.030
The pebble road potholes	0.035~0.050
Dry compaction dirt road	0.025~0.035
The compaction dirt road after the rain	0.050~0.150
Muddy dirt road	0.100~0.250
Dry sand	0.100~0.300
Wet sand	0.060~0.250
Compaction of trail	0.030~0.050
Icy roads	0.015~0.030

5.1.2Air resistance ARF

$$ARF = \frac{C_D \times A \times {v_r}^2}{21.15} \qquad (5\text{-}11)$$

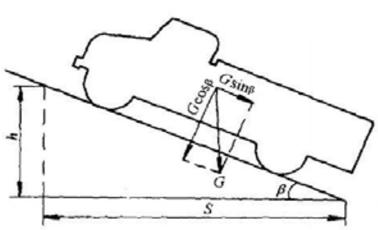
Driving a car in the air medium it relative to the air movement, air force on the directional component is called air resistance. Air resistance coefficient C_D can be measured by the road test, wind tunnel tests and other methods.Automotive windward area A commonly used wheel track product the height. Relative speed car and air is said v_r . (chart-2) .

Chart-2 air resistance coefficient and windward area

vehicle type	windward area	air resistance
typical car	1.7~2.1	0.30~0.41
truck	3~7	0.6~1.0
Bus	4~7	0.5~0.8

5.1.3Grade resistance GF

$$GF = G \sin \beta$$



Figur

When the car was going uphill,the component of car's gravity in the direction parallel to the road surface(Fig. -1),known as the grade resistance.When the road grade β is smaller can be approximated by $\sin\beta \approx \tan\beta$.

$$GF = G \tan \beta \qquad (5\text{-}13)$$

Ratio of slope height and bottom length is said to road grade.

$$i = \frac{h}{s} \qquad (5\text{-}14)$$

$$GF = G \times i \qquad (5\text{-}15)$$

According trigonometric relationships, when the degree of slope less than or equal to 10 degrees using the equation of 5-15 to calculate,others else using the equation 5-12.

5.1.4Mechanical efficiency of transmission η_t

Automobile engine output power through the transmission to the process of driving wheels, part of the power be used to overcome friction in transmission (for example, transmissions, majority decelerator, meshed gear loss, etc.) So the ratio of the power of power-train and the output power of the engine can be defined as the mechanical efficiency .Although it is influenced by many factors,when analyzing it can be take as the constant.As shown in chart 3.

Chart-3 Mechanical efficiency

Vehicle type	Mechanical efficiency value
car	0.9~0.92
Single-stage truck	0.9
Two-stage truck	0.85
4×4automobile	0.85
6×6automobile	0.8

5.2Calculating the speed of the engine

Rotate speed is one variable of the fuel consumption prediction model , during the test, recording the gear.Assuming that between the wheel and the road does not slip or slide,The following equation can be used to calculate the rotate speed of the engine.

$$RPM = \frac{60 \times v \times DRT \times GRT}{\pi \times TD}$$

5.2.1The calculation of the unit fuel consumption

Theoretical model of fuel consumption is the unit fuel consumption is that the car uses the fuel in every second . The following equation can be used to Calculate.

$$UFC = FC / T \qquad (5\text{-}17)$$

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5.2.2To solve the unit fuel consumption model

According to a large number of field fuel consumption test, the parameters of the model can be demarcated, in view of the external power is greater than zero and less than zero two cases, be demarcated in two steps.
First ,using the negative power of fuel consumption data to demarcate UFC_{io} and α_3. Second,using the experimental data of experimental power of fuel consumption, rotate speed and output power to demarcate α_1 and α_2.Finally ,getting a integral fuel consumption model.

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