An Analysis of Driving Fuel Consumption about Different Type of Roads

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Abstract—This study focuses on the vehicle’s fuel consumption analysis for various type of road characteristics. The research, using G-sensors, Gyro and OBDII to get driving data and fuel consumption information, explores the fuel consumption for different types of roads such as flat roads, highways, roads in urban area and circumferential roads. The factors related to fuel consumption, such as the traffic light setting and the slope of a road are studied. In this study, we employ the use of statistical methods for the analysis results, and we also use statistical charts to present the study results. This study can be applied in road situation analysis, traffic light designs, traffic navigation and traffic safety information.

Keywords—Road fuel consumption analysis, OBDII, Traffic lights and fuel consumption, Data warehouse.

I. INTRODUCTION

In this paper, we check for some road features and driving fuel consumption, with respect to changes in road conditions that affects driving speed as a result makes fuel consumption various. First, we use a driving data recorder, with GPS unit and MEMS unit, to collect driving spatial-temporal data and driving behavior data first. We then use OBDII to get driving fuel consumption information. These data are then transformed into a road dynamic situation set. The road driving situation data are deposited into a data warehouse. We develop various indexes to analyze road features and fuel consumption situation.

This study carried out investigations and analysis for the indicators about traffic light and the fuel consumption. Traffic lights usually cause a critical impact on fuel consumption on the roads. This paper discuss some research results in accordance with the driving in stop traffic light on fuel consumption. The study thus helps the drivers by providing some navigation information about dynamic road situation of fuel consumption related with traffic light design.

The other study in this paper is on analyzing the relationship of the road situation about forward-backward acceleration, and lateral acceleration vs. fuel consumption. To generate the lateral acceleration on the road the car is mainly caused by the rotation of the steering wheel between the traveling, and the steering wheel for vehicles passing through the road camber, therefore exploring the relationship between curvature of the road, straightness and fuel consumption can be regarded as one of the road’s characteristics, so curved road is not compare to the fuel, which is a topic worth exploring. There is discussion about the slope and fuel consumption, the road has the downhill or the uphill type, we analysis uphill than downhill with respect to the fuel consumption, so on the downhill road features can also be regarded as a characteristic. If an uphill’s fuel consumption is more than that of a downhill then how is the difference between the fuel consumption compared? This will be to do a study for route planning and fuel consumption relationship, unit fuel consumption values using different routes, to do model analysis algorithms, by using algorithms road do unit fuel consumption to make a leaderboard, providing a better route choice to the user. In the end, according to the previous analysis theme to make a conclusion, and also distinguish from comprehensive analysis of fuel consumption for road features, and do a conclusion to provide when planning vehicular navigation or traffic unit road planning.

II. BACKGROUND & LITERATURE

In [1], the affection of driving behaviors to the fuel consumption is studied through analysis of driving data using machine learning approach. Several indices related to the driving behaviors extracted from the driving data are proposed.

In [3], Jun-zhe Yang develops a study entitled “GPS/INS combination of trajectory reconstruction analysis system. He develops establishment of a data warehouse analysis, rule-
Base test data, based queries in space, erection of a complete system analysis platform.

In [7], several driving factors relevant to fuel consumption are proposed. They are classified into two clusters, road dependent factors and driver dependent factors, using neural networks and regression analysis.

In [8], Yi-liang Tsai, Road features lane Using the digital event data recorder to collect vehicle information, include road curvature, road interference, road smoothness that three indicators.

Other subjects of this research paper on road fuel consumption analysis, such as traffic lights and fuel consumption relationships, the road curved relationship of the degree of fuel consumption and road slope and fuel consumption relationship are being explored.

**Single-factor analysis of variance**

In this study, ANOVA is used to identify dependent variables, to find out whether there are differences for the analysis of variance of the experimental design and to eliminate the interference of the unknown factors which can be observed only in respect to the effects of specific factors, thereby improving the results of the analysis’ accuracy. Significant differences in one-way ANOVA analysis for various road characteristics and in doing this research’s purpose is to be able to distinguish between varieties of different road characteristics.

**Data Mining**

Data mining is to extract meaningful information from a large amount of seemingly meaningless data through clustering mechanism, such as classification, cluster grouping mechanism data clustering. With well-known clustering algorithms, Decision Tree and K-means Clustering Algorithm, this study hope to see whether there is a correlation between these roads after clustering their characteristics.

III. **RESEARCH FRAMEWORK AND STATISTICAL ANALYSIS**

3-1. **Research framework**

In this study, the framework is to explore a variety of road fuel consumption scenarios, because the characteristics of the fuel consumption varies for each road, we will explore in fuel consumption analysis for the following four; Indicators and fuel consumption, traffic lights and fuel consumption, the road lateral acceleration and fuel consumption, and also the road grade and fuel consumption.

(1) **Driving Data Collection(Automatic vehicle location and OBD II)**

In this study we want to effectively identify the various road behaviors’ characteristics for the fuel consumption and its impact with a certain degree of correlation. The experimental design and planning is divided into different road characteristics based on the experimental data collection. In order to obtain the relationship between the different road characteristics and their relation to fuel consumption, we used digital event data recorder and the OBDII fuel consumption extraction software to collect information which is been converted from the raw data to an excel file that is easily readable.

(2) **Indicators and fuel consumption analysis**

When traveling on a variety of different sections, the fuel consumption would not be the same; each section has its own traffic flow, traffic interference and these factors do not only cause the slowing down below the average of speed but also waste fuel. In this research paper we hope to explore more with the flat roads, and the case for the various sections of the fuel consumption.

(3) **Analysis of the traffic lights and fuel consumption**

Traffic lights are an important characteristic of the plane road. A road segment has more traffic lights will result in more waiting time and thus more fuel consumption. In this case, one may focus on it in two sub-themes;

3-2. **Data collection**

We set up a Digital Tachograph and an OBD2 to collect the data from the car. The Digital Tachograph collected the data including Longitude and Latitude coordinates, GPS speed, driving angular velocity and speed, and the X-axis acceleration (longitudinal acceleration) and Y-axis acceleration (lateral acceleration). For the fuel consumption data used an OBD2 agreement that is linked to trip computer read driving information, and using a notebook computer to do the link for the collection of the throttle opening. The fuel consumption data and the digital event data recorder’s overall Chart, as Figure 3.1.

![Figure 3.1: The Architecture of Driving Data Collection in Vehicles](image-url)
3-3. Road Traffic Data Warehouse

This study will like to use the cloud system to analyze the collected data by the Automatic vehicle location and the OBD2. To analyze traffic information and fuel consumption data with the several road traffic conditions, as we already have all the information with the fuel consumption from the Automatic vehicle location information. Architecture for road traffic data warehouse system can now be developed to facilitate the management and storage of road integration of information. In data warehouse for data analysis or query analysis, steps through this analysis process is a way to provide multi-dimensional fast query tool, it provides Roll-Up, Drill-Down, Slice & Dice and Pivot. The following is a brief description about the four functions as in Figure 3-2.

Roll-Up: Roll-up function is similar to the Bottom-Up approach which aggregate statistical information presented by a complete detail (Example: you can move up from the daily data to the week, and then up again to pull the quarter by week)

Drill-Down: Drill-Down situation is opposite to the pull-down. To a detailed information from the integrated query action by the Top-Down (Example: in a trip curvature down pulled hour, pulled every minute and then down, then down pulled per second).

Slice & Dice: Exploration of an information-oriented way.

Pivot: The original cube box on different axis will present another query block.

The distribution of total fuel consumption in some road type is wider than the others, i.e. the fuel consumption in such road is much unstable.

4-2. Traffic lights and fuel consumption explore

In this section, we want to explore the amount of fuel consumption caused by stop-and-wait for traffic lights. Using per second from the cumulative amount and speed to understand whether the traffic light junctions had stop action, methods is per second from the cumulative difference, and the distance cumulative difference less than 0.001 km, and the stagnate time up to 20 seconds or more, the research hypothesis rate of encounter traffic lights, the speed will slowly down to zero, and the waiting, after traveling speed will be increased to the original speed, take
the situation of the roads and fuel consumption, all fuel consumption values can refer to the following figure, according to the experimental data can know the waste of fuel consumption in different sections (Figure 4.5), of wasting the amount of fuel consumption possible because to the number of traffic lights stopped, or equal to the number of seconds the length of.

The frequency of driving pauses for traffic light is close related to the fuel consumption. The three phases in a driving pause are deceleration, stop-and-wait and acceleration. Since the speed is zero in the stop-and-wait phase, in the following, we only analyze the fuel consumption in deceleration and acceleration phase. Four routes with road characteristics flat road, highway, road in urban area and circumferential road, referenced as R1, R2, R3 and R4 respectively, are selected to collect driving data. The driving data for each route includes number of driving pauses, driving time, distance and fuel consumption.

In the experiment, a continuous time period of driving data is recognized as a driving pause for traffic light if the speed is no greater than 30 km/h (the threshold set in this experiment) in the whole time period, the speed decreasing to zero (the deceleration phase), then staying zero for at least 15 seconds (stop-and-wait phase) and then increasing to exceed the threshold (acceleration phase). In the analysis, the required driving data includes the number of driving pauses, and total time (ST), total fuel consumption (SF), total driving distance (SD) in phases extracted from the driving data in driving pauses, as well as total fuel consumption (TF), total time (TT), total distance (TD) in route driving and number of traffic lights in the route.

Several indices are considered in the following analysis. RF = SF/TF is the fuel consumption ratio, RD = SD/TD is the distance ratio, and RT = ST/TT is the time ratio of a phase of driving pause to the whole route driving. Let SSV denote the total absolute speed variation in a phase, which is defined as $\Sigma t(|V_t|)$, where t is over the time in a phase of driving pauses and $V_t$ is the difference of driving speed at time (in second) $t$ and $t+1$.

The following is the fuel consumption analysis in deceleration phase. First, observe the plots for RF vs. RD and RF vs. RT.

Figure 4.3: Plot of RF vs. RD   Figure 4.4: Plot of RF vs. RT

Figure 4.3 shows that for each route, higher RD is associated with higher RF. It implies the positive correlation between RD and RF. Figure 4.4 presents a linear relation between RF and RT.

Figure 4.5: A plot of SF vs. SSV/SD

Figure 4.5 is a plot of SF vs. SSV/SD. It shows as SSD/SD getting higher the fuel consumption rate getting lower drastically. It means in a driving pause for traffic light high speed variation results in high fuel consumption. The analysis conclusion is consistent over all trips.

In the following, we take fuel consumption analysis in the acceleration phase. First, observe the relation between SSV and SF under smooth acceleration assumption.

Figure 4.6: Fuel consumption vs. $\Sigma ST(|V_t|)$
Figure 4.6 shows the positive ratio trend between the speed variation and fuel consumption. For more detailed observation, the data of each route is shown in distinct figure in the following.

From the above figures, for each route the trend of positive ratio between the speed variation and fuel consumption is even clearer, however, with different regressive slope.

In precise, slope for R2 > slope for R3 > slope for R4. When encountering traffic light, the acceleration phase is smoother in route R4. However, in route R2 and R3, more than one pause could happen for passing a traffic light, which causes stagnation in the acceleration phase.

From the above Figures, as complete driving data in acceleration phase presented, there are outliers. For example, on routes R2 and R3, some SSV values exceed 300, which means there are traffic jams in front of traffic light and the vehicle cannot pass the traffic light after one pause. After removing the outliers, on route R3, there still are SSV values exceed 100, which means the stagnation in the acceleration phase caused by jams in front of traffic light.

Finally, let us discuss the correlation between SSV/SD and SF.
From Figure 4.11, the inverse ratio between SSV/ST and SF can be observed. If the vehicle can accelerate to the normal driving speed in a short time, then the fuel consumption will be less. A longer acceleration phase usually means that the vehicle cannot pass the traffic light in one driving pause and thus may cause more fuel consumption. That is caused by jams in front of traffic light or improper time setting of traffic light.

Next, consider the plots of SSD/SD vs. SF.

Comparing the plots of SSV/SD vs. SF for the four routes, one will find that the data points lie almost in a horizontal line with different level for routes R2, R3, R4. It implies that the fuel consumption rate is almost independent on the speed variation in unit distance in a route. The fuel consumption rates distribute from 0.4 to 1.0, grouped into three clusters of high, median and low fuel consumption rate, corresponding to the three routes respectively. It thus can be an indicator of road characteristic on traffic light.

4.3 Slope of Road vs. Fuel Consumption

In this analysis, the driving data of the route of highway characteristic are used. The driving data is partitioned into three segments, each of which is uphill or downhill. In each segment, the driving time, speed, fuel consumption, and the location are collected. The road slope is also calculated as following.

\[ \text{Slope} = \frac{H_{\text{start}} - H_{\text{end}}}{d}, \]

where \( H_{\text{start}} \) and \( H_{\text{end}} \) are the height of start and end location of the trip respectively, and\( d \) is the driving distance of the trip in kilometer. The uphill segment is one with positive slope and downhill segment is one with negative slope.

From Figure 4.12, the average fuel consumption rates of uphill trip are obvious higher than those of downhill trips. The ratios of fuel consumption of uphill to that of downhill trips of road segments are 1.3, 1.5, and 1.5 respectively. In other words, the differences of fuel consumption rate are about 30% and 50%.

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Figure 4.14 shows approximate linear relation between slope change in unit distance and fuel consumption rate for each road segment. In traffic jams, the slope factor still affects the fuel consumption, which can be observed from a number of dispersed data in the Figure 4.14.

The larger slope changes, the larger uphill/downhill fuel consumption changes. According to the real data, as the difference of slope is around 100, the difference of fuel consumption is about 0.7. Based on the above discussion, the road slope does affect the fuel consumption when the road segment is sufficiently long. In general, the ratio of fuel consumption between uphill and downhill road segment is about 0.5 to 0.7.

![Figure 4.15: Fuel consumption vs. average speed and slope](image)

Next, we will investigate the relation between driving speed, road slope and fuel consumption. In previous research on fuel consumption, the highest fuel efficiency speed is 90 to 100 km/h, the lowest fuel efficiency speed is 20 to 50 km/h, and median fuel efficiency speed is from 50 to 90 km/h.

The conclusion can be applied to road design for fuel efficiency. A road designed with less slope change will save fuel.

4-4. Grading Some Roads Based on Fuel Consumption Data

Through experimental planning with the hope of finding a slope with a significant different road characteristics, in this way we can observe that the fuel consumption is not of a significant difference, so we take a look at a trip to and fro of the highway between Linkou Interchange and Yangmei Interchange to see if there is any difference in fuel consumption. Experimentally, the route from Linkou to Yangmei can be divided into three sections, Yangmei to Youshi (See Annex Table 4.4), Taoyuan to Linkou (See Annex Table 4.5) and Youshi to Taoyuan (See Annex Table 4.6). Apparently, the slope of this highway can be seen from these three sections; from Yangmei to Youshi is in an uphill state, Youshi to Taoyuan is a long distance downhill state, and there is a little change in slope between Taoyuan to Linkou which is in a climbing state.

From the results of the analysis, we can observe that a speed range of 40 to 60 is seen in the uphill section from our experiment than that of a downhill section. This can also prove that the speed is slower in an uphill section and faster speed is seen in a downhill section. This shows a concentration on the right portion of the graph in Figure 4.11. On the Y-axis of the curve shows that fuel consumption in is low for the uphill section than the downhill section. This means that the uphill section does well in terms of fuel than in the downhill section.

![Figure 4.16: Slope of road vs fuel consumption rate](image)

V. ROAD SELECTION FOR ECONOMIC FUEL CONSUMPTION

The study for the analysis on the use of units of fuel consumption of different roads can be used to choose the best route of four different routes using the algorithm. And finally using the algorithm to analyze what driving route is best for the user.

5-1. Algorithm

Step 1 All possible routes from point A to point B are listed, and based on the total fuel consumption of each route, they can then be sorted from the highest to the lowest, and number each row starting from 1 to n.

Step 2 Regardless of the maximum Number n is even or odd, both to the sub from high to low Sort.

Step 3 The sum of the scores for each route as each route points, the integral descending Sort.

Step 4 Directions integral sort results of the fuel consumption for each way; one may select the route which has minimum summation of the ranking numbers.

An experiment is conducted on routes starting from Yuan-Ze University to Yangmei Train Station. Four different routes are used: No. 1 is a highway, and No. 2, No. 3 and No. 4 are flat roads.
A running example is shown below. Consider one start from point A to point B, and this experiment consists of four different routes from point A to B, each route has been repeated three or four time. The collected fuel data is list below: R1(1.44), R1(1.28), R1(1.41), R1(1.23), R2(1.34), R2(1.59), R2(1.35), R3(1.17), R3(1.12), R3(1.08), R3(1.12), R4(0.87), R4(1.19), R4(1.29), R4(1.26), as shown in Figure 5.1.

![Figure 5.1: Total Fuel Consumption of Each Run for Different Routes](image)

Using the algorithm provided above, one may get a ranking score list as R2(11.6) > R1(9.7) > R4(5.5) > R3(3). Thus, the road R3 is selected, which provides the most economic driving fuel consumption.

VI. CONCLUSION

In this study, we mainly focus on the fuel consumption of different roads based on their characteristics, and rank them based on the unit fuel consumption of these roads. We then generate a data warehouse of road driving situations, and using the XY scatter chart we can observe the speed indicator and the unit fuel consumption for various road characteristics. Also bringing to light is the impact of traffic lights on fuel consumption, estimated the ideal traveling time (seconds) and fuel consumption with the absence of traffic light. Then the influence of road curvature on fuel consumption as well as the influence of slope on fuel consumption.

Finally, with the route planner, the user can make a better choice when doing a route planning using our approach.

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