

Statistics, Monitoring and Evaluation System for Energy Consumption and CO₂ Emission in Highway Freight Transportation

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Abstract. This paper is to establish a comprehensive system combining statistics, monitoring and evaluation of energy consumption and CO₂ emission, which is to obtaining the real-time traveling geographical coordinates and energy consumption by using mobile vehicle-mounted terminal. It allows transport authorities and local governments obtaining real and reliable energy consumption and CO₂ emission data, to make foundation for evaluation works, to instruct and promote local transport authorities to implement key tasks required by the State and MOT and to provide guarantee to realize national energy-saving and emission reduction targets.

Introduction

With regard to greenhouse gas emission, China is among the major big counties. Transport serves as one of the key industries in China's energy consumption and CO₂ emission, as well as the key sector for the Chinese government to implement the task of energy saving and emission reduction. In China, freight transport plays a significant role in energy consumption and carbon dioxide emission in the transport field. The amount of energy and fuel consumption in China's transport sector account for 8.4% and 40.0% respectively in 2013 [1]. The CO₂ emission made up for around 15% of the total social volume, in which freight transport accounted for over 50% of the total emission volume in the transport field. With the accelerating pace of China's industrialization and new-type urbanization, transport, especially freight transport has gained the increasing momentum for energy consumption in terms of total volume and intensity.

However, at the current stage, the system of statistics, monitoring and evaluation of energy consumption and CO₂ emissions is underdeveloped in the transportation field in China. Especially, the statistics of the freight transport by highway, which accounts for highest proportion in total transport energy consumption, has yet to be solved. The basic data for statistics and monitoring of operational freight vehicle is weak, presented in three aspects: firstly, it is difficult to collect data due to huge amounts of enterprises but with small scale, wide spread and weak capacity; secondly, data collection mainly adopt the manual method by informant, which results in difficult evaluation and review; and, thirdly, the enterprises under the coverage of statistics system are not sufficient and representative enough.

Generally speaking, the traditionally statistics and monitoring system is backward and data quality cannot be guaranteed. It is quite difficult to collect relevant data in highway freight transport field if using traditionally methods, thus results that the transport authorities have no foundation to evaluate energy-saving and emission-reduction level. Therefore, aiming to settle above issues, it is necessary to establish the statistical, monitoring and evaluation system for energy consumption and CO₂ emission in transportation field under the government's statistical framework. By monitoring trucks, the real energy consumption in transportation field, as well as the progress of energy-saving will be evaluated, which can provide real and available information to make relevant policies.

System Structure

The conception of statistics and monitoring system for highway freight transport is to obtaining the real-time geographical coordinates, vehicle speed, mileage, energy consumption, etc. automatically by using mobile vehicle-mounted terminal. There are five parts of statistics and monitoring system, which including mobile vehicle-mounted terminal, network, gateway, back-end server and front-end client. In particular, vehicle-mounted terminal collects data and transfers to the gateway with wireless network through the TCP protocol. And then gateway parses and then stores to the database server. Finally, the user reads data through front-end client. The various parts of the system architecture should meet the following requirements.

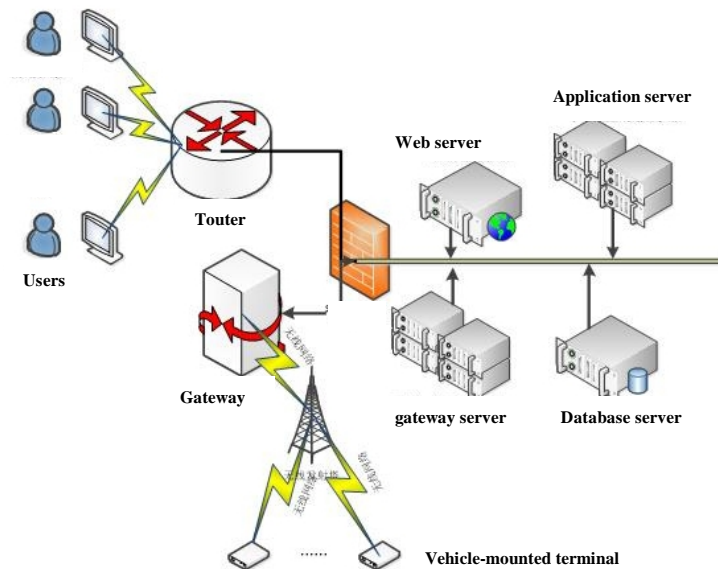


Fig. 1 Overall Plan Design

Vehicle-mounted terminal should include fuel level sensor, the satellite positioning module, wireless transmission module, real-time clock module, etc. By using the vehicle-mounted terminal, real data like vehicle positioning, mileage and energy consumption can be acquired timely.

The gateway carries out data interaction with vehicle-mounted terminal by using SOCKET long connection, core work of that is to parse the real-time data uploaded by terminal and save the data. The gateway should have functions of data reception, data parse, order data issued, etc.

The back-end server is the infrastructure to support the system operation which including database server, application server, storage equipment, network equipment and safety equipment. It achieves the data processing system, storage and application, to ensure the system functions smoothly and safely.

The front-end client is a platform interface that faces to user and realize the function of the system. The platform should achieves the real-time data acquisition and display, map operation, data analysis and abnormal alarm, etc.

Research on Fuel Consumption Algorithm and CO₂ Emission Conversion

Collection principle of fuel consumption. The fuel consumption data uploaded by vehicle terminal is obtained by voltage signal of fuel level sensor. Figure 2 shows the collection principle of fuel voltage signal, in which, R_0 is divider resistance; R_x is the resistance corresponding to residual fuel quantity in the oil tank; and U_i is the fuel voltage signal. The vehicle terminal collects the fuel voltage signal U_i transferred between the fuel level sensor and the instrument panel by fuel signal wire. The signal is subjected to A/D switching, filtering, amplifying, etc. And then the fuel consumption data and others (like geographical coordinates, vehicle state parameter) are sent to the statistics and monitoring system.

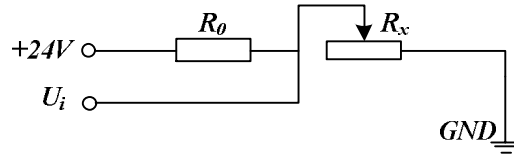


Fig. 2 Collection Principle of Fuel Voltage Signal

Different kinds of trucks have different shapes of oil tanks, so each kind of truck must be subjected to fuel consumption calibration so as to obtain the conversion relation between the fuel voltage signal of each kind of truck and the residual fuel consumption in the oil tank.

Algorithm research. In the past, the fuel quantity of truck are always calculated by traditional manual calculation method. This paper proposes the automatic detection algorithm of the fuel quantity obtained by fuel level sensor in order to improving the precision of fuel quantity and work efficiency. The vehicle terminal can monitor the residual fuel quantity of truck in real time.

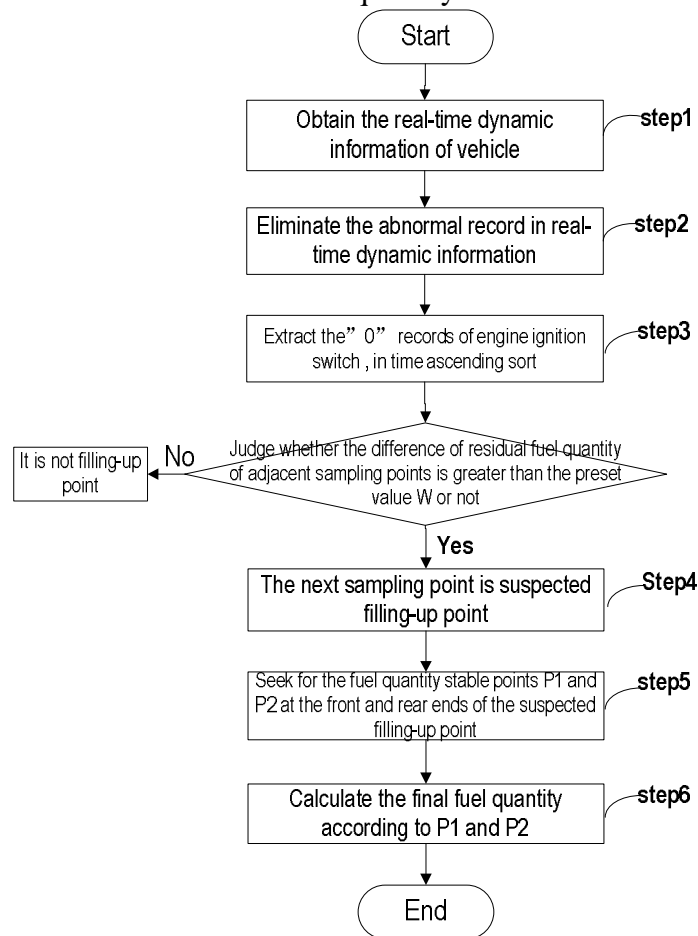


Fig.3 Algorithm Flow

Step 1, for obtaining real-time dynamic information shall at least include collection time, residual fuel quantity, AD value, mileage and ignition switch state.

Step 2, eliminating abnormal data include:

The first real-time information after the state of engine ignition switch switched to 0 from 1;

Real time information when the fuel quantity voltage value is higher than 80% of the set maximum voltage value or lower than 20% of the set minimum voltage value;

Real time information when the engine ignition switch is empty and the residual fuel quantity is zero or empty;

Step 3, extract the real time information of vehicle with engine ignition switch state of "0"; and the real time information is in ascending sort based on the collection time;

Step 4, successively compare the residual fuel quantity of adjacent sampling points; compare the difference of the two sampling points with the preset value; if the residual fuel quantity of the next

sampling point is greater than that of the front sampling point and the difference is greater than the preset value, the next sampling point of the two adjacent sampling points is suspected filling-up point;

Step 5, According to the suspected filling-up point, the step for calculating the stable points P1 and P2 of front and back the filling-up point is as follows:

(1).Find several arrays before and after the suspected filling-up point; and each arrays composed of N residual fuel quantity sequences.

(2).Find the average value of N residual fuel quantity in each array;

(3).Find the change rate K of residual fuel quantity of adjacent groups;

$$K_{before} = \left| \left(\frac{1}{N} \sum_{i=1}^{i+N-1} Y_i - \frac{1}{N} \sum_{i=1}^{i+N} Y_i \right) \times 100 \div \frac{1}{N} \sum_{i=1}^{i+N} Y_i \right| \quad (1)$$

$$K_{after} = \left| \left(\frac{1}{N} \sum_{j=1}^{j+N} Y_j - \frac{1}{N} \sum_{j=1}^{j+N-1} Y_j \right) \times 100 \div \frac{1}{N} \sum_{j=1}^{j+N-1} Y_j \right| \quad (2)$$

$$i \geq 1, j \geq 0$$

In which, K_{before} is the change rate of residual fuel quantity of adjacent two values before the suspected filling-up point; K_{after} is the change rate of residual fuel quantity of adjacent two values after the suspected filling-up point; Y_i is the residual fuel quantity of i sampling point before the suspected filling-up point and adjacent to the suspected filling-up point; and Y_j is the residual fuel quantity of j sampling point after the suspected filling-up point and adjacent to the suspected filling-up point.

If two continuous K_{before} is less than or equal to the set value of the change rate, the first stable point P1 before the suspected filling-up point is the sampling point participating in K_{before} calculation and nearest neighbor to the suspected filling-up point. If two continuous K_{after} is less than or equal to the set value of the change rate, the second stable point P2 after the suspected filling-up point is the sampling point participating in K_{after} calculation and nearest neighbor to the suspected filling-up point.

Step 6, the method for calculating fuel quantity by P1 and P2 is as figure 4.

CO₂ emission conversion model. Carbon dioxide emission is calculated according to CO₂ emission model published by IPCC.

$$C = \sum A_i \times EF_i \quad (3)$$

In the equation:

C -- CO₂ emission

A_i -- consumption of the i kind of fossil fuel

EF_i -- emission factor of the i kind of fossil fuel

EF_i = lower heating value * carbon content * carbon oxidation * carbon conversion coefficient

CO₂ Emission Coefficient. There are default emission factors for stationary combustion in the energy industries in Volume 2 Energy of Chapter 2 Stationary Combustion in <Guidelines for National Greenhouse Gas Inventories>, each energy is calculated with TJ. In China, it has been used to carry on statistics with standard coal (the definition of standard coal is: any amount of fuel, which can provide 29.271MJ(7000kcal/kg), is converted into 1kg standard coal). In calculation, CO₂ emission factor shall be converted into CO₂ emission coefficient. CO₂ emission coefficient of each kind of energy, after conversion, is shown as table 1.

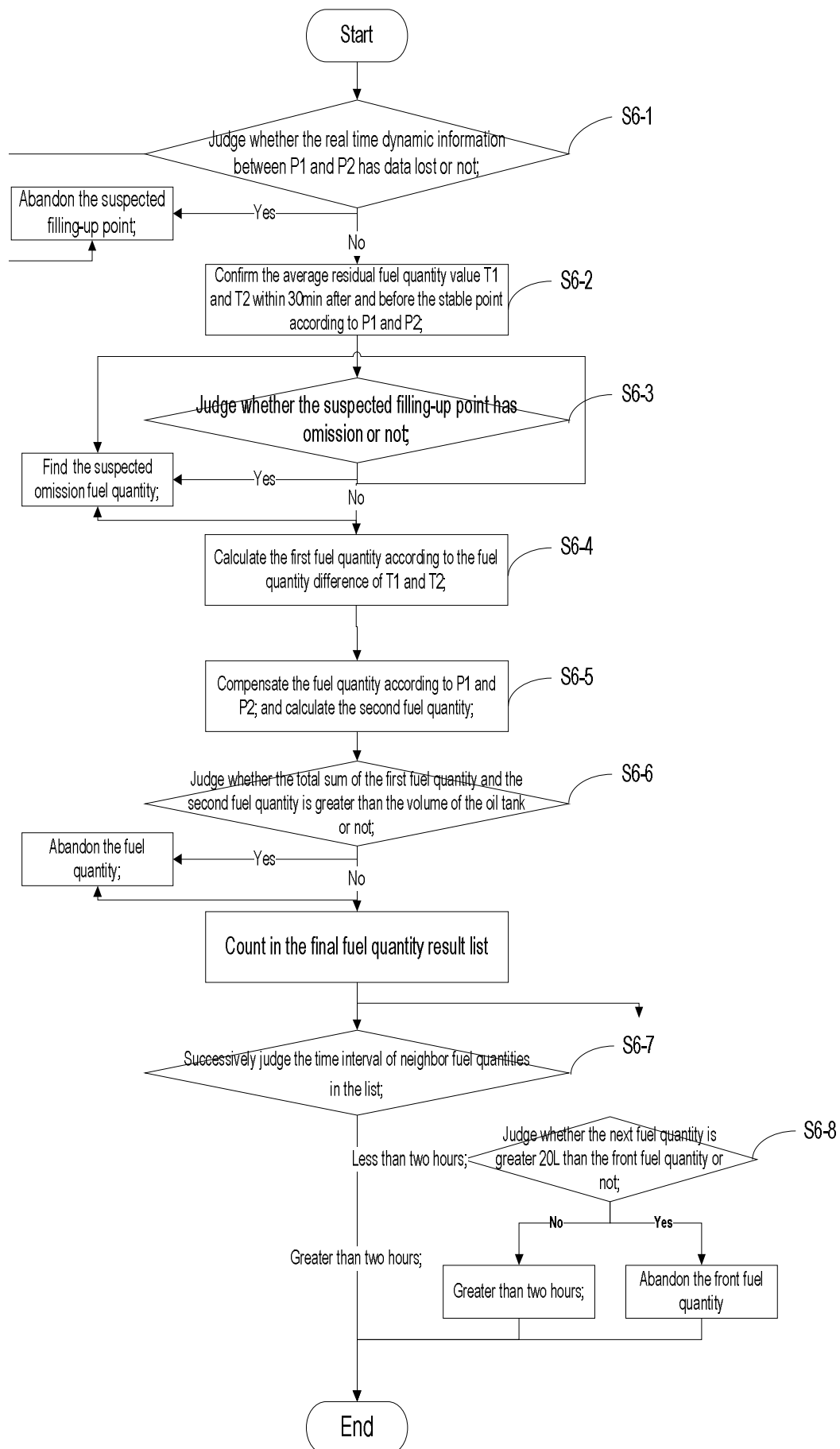


Fig.4 Algorithm flow of Step 6

Table 1: Carbon Emission Coefficient of Energies [2]

Fuel	Standard Coal Conversion Coefficient		CO ₂ Emission Default Value	CO ₂ Emission Coefficient	Calculation Unit
Petrol	1.4714	Kg Standard Coal/Kg	69300kg/TJ	2.9848	T CO ₂ /T
Diesel	1.4571		74100 kg/TJ	3.1605	T CO ₂ /T
Fuel Oil	1.4286		77400 kg/TJ	3.2366	T CO ₂ /T
liquefied petroleum gas	1.7143		63100 kg/TJ	3.1663	T CO ₂ /T
Natural Gas	1.33	Kg Standard Coal/M ³	56100 kg/TJ	2.1840	Kg CO ₂ /M ³
kerosene	1.4714	Kg Standard Coal/Kg	71900 kg/TJ	3.0967	T CO ₂ /T
Coal	0.7143		97500 kg/TJ	2.0385	T CO ₂ /T

Fuel Consumption Experiment

After vehicle terminal are installed, drivers provide real fuel quantity according to receipt provided by gas station. With feedback of investigation of 5 trucks real fuel quantities data within two months, 68 real fuel quantities data were acquired. Fig.5 is comparison of real fuel quantities and fuel quantities monitored by the vehicle-mounted terminal, monitored fuel quantity is abscissa, real fuel quantity is ordinate, all 68 coordinate points concentrate near the line of $y=x$, and correlation index of two groups of data is 0.985 through calculation, which indicates vehicle terminal equipment has higher precision.

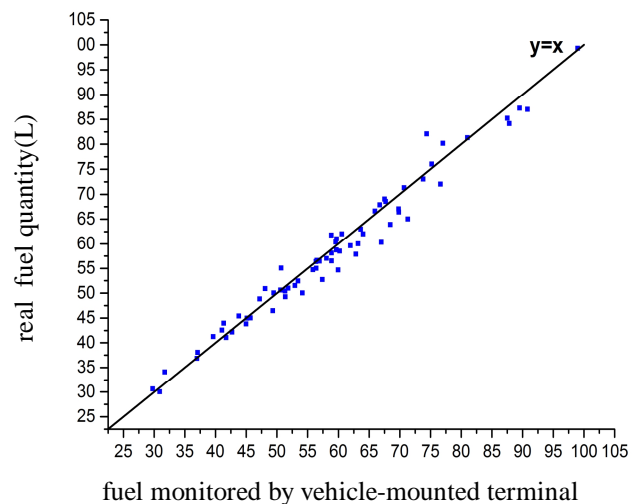


Fig.5 Fuel Quantities Comparison

Table 2 is fuel quantity precision figure made with statistical data of 4 types of trucks, so it indicates that the average precision of 4 types of trucks are all above 95%. Error frequency distribution statistics for different type of vehicles is performed shown as Fig.6- Fig.9, which shows that monitoring error under $\pm 10\%$ from FOTONBJ5049XXY-F3 van truck, Isuzu ELF series truck, Isuzu QL5070XHKXR van truck and JAC HFC5081XXYKT van truck takes separately 87.37%, 96.08%, 95.28% and 96.69% of the total. From the above statistics, monitoring errors of 4 types of trucks for one fuel quantity are all basically within 10%.

Table 2 Fuel Quantity Precision of 4 Types of Trucks

Types of Truck	Vehicle Quantity	Refueling Times	Real Fuel Quantity(L)	Estimated Fuel Quantity (L)	Average Error (%)
FOTON BJ5049XXY-F3	2	26	1313.81	1317.849	0.31
Isuzu ELF series truck	1	15	879.14	881.667	0.29
Isuzu QL5070XHKXR	1	21	1251.6	1290.088	3.08
JAC HFC5081XXYKT	1	6	522.024	517.35	-0.90

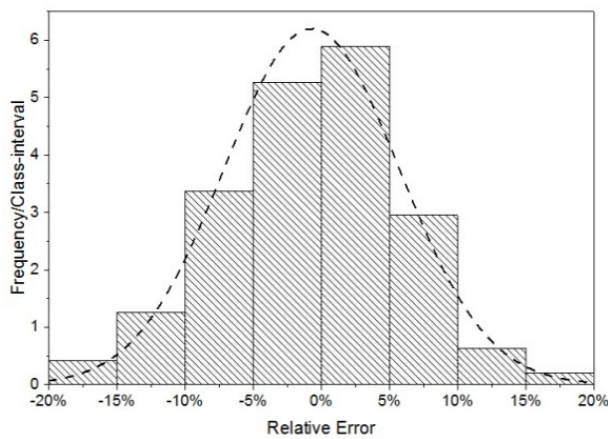


Fig.6 FOTONBJ5049XXY-F3 Truck

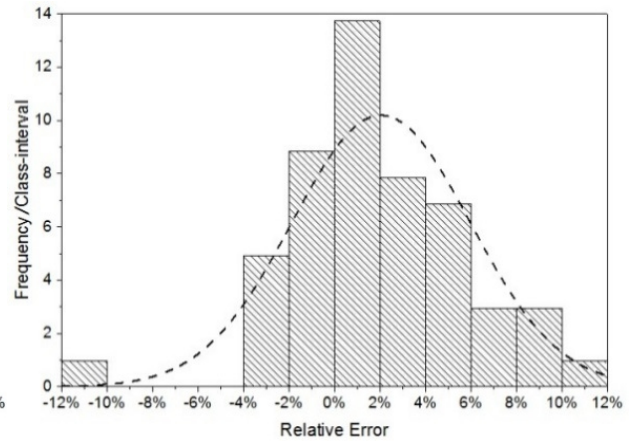


Fig.7 Isuzu ELF Series Truck

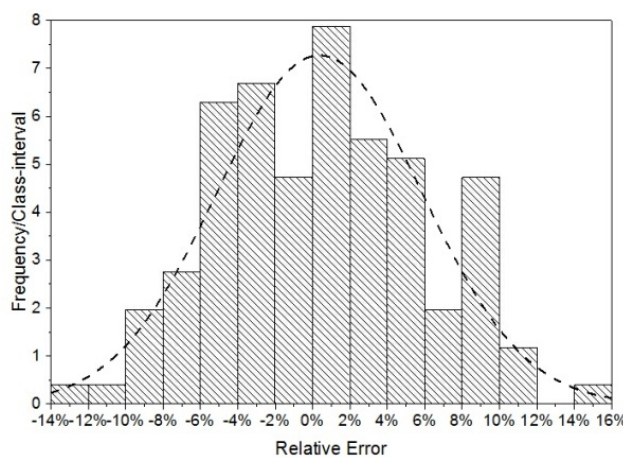


Fig.8 Isuzu QL5070XHKXR Truck

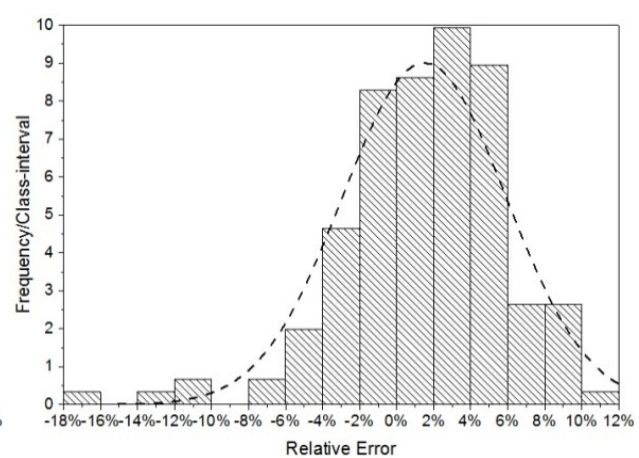


Fig.9 JAC HFC5081XXYKT Truck

With data analysis comparing with real-time fuel consumption monitored by terminal and real fuel quantities, it is proved that the vehicle-mounted terminal has high precision on fuel, which can meet requirements of long-term and large-scale truck fuel consumption monitoring. Besides, because of the terminal gathered fuel quantity information from original fuel level sensor of the truck, no extra sensor needed, cost of fuel consumption are highly reduces, so the vehicle-mounted terminal has good economic feasibility.

Conclusions

This paper is to establish a comprehensive system combining the statistics, monitoring and evaluation of energy consumption and CO₂ emission in highway freight transportation, which allows transport authorities and local governments obtaining real and reliable energy consumption and emission data, to make foundation for evaluation works, to instruct and promote local transport authorities to implement key tasks required by the State and MOT and to provide guarantee to realize national energy-saving and emission reduction targets.

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