

# Evaluation of an In-Motion Vehicle Weighing Method via Grey Estimation Model

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(Received November 1, 2001)

## Abstract

A novel weighing method for in-motion vehicles is set up in this paper. The measurement principle is described and the estimation for measurement uncertainty by Grey Error Theory is presented. Theoretical analysis and experimental research show this method can be used to solve the weighing problem for in-motion vehicles with a rather high accuracy.

**Keywords:** Vehicle weighing, Measurement uncertainty, Grey estimation

## 1. Introduction

With the development of transportation and carrying trade, the number of over-loaded vehicles and their speed has got larger and larger. The weighing of in-motion vehicles is becoming very important for traffic supervision and control in nowadays. The strict regulations for the load and speed of in-motion vehicles would thus be necessary because the over-loaded vehicles and their high speed would probably cause serious problems such as damage to the roads, public nuisance due to noise or vibration and, what is more, they could be one of the hidden troubles of the serious traffic accidents [1,2].

The weighing instrument used to control the over-loaded vehicles in many highways is usually axle-weighing system. This system gives the total weight of a vehicle by measuring each axle weight as it passing through a specific road - weighbridge. Taking the vibration component caused by the motion of vehicle into account, the measured signals are used to estimate the total weight.

In recent years there are some new methods and theoretical approach in dynamic mass (weight) measurement [3,4]. Among them the Frequency-Controlled Method [5] is one of the more accurate method. Therefore it is more desirable for mass measurement under weightless conditions.

In this paper we proposed a practical weighing method. This method is applied to the real data of cab-over-engine trucks in many different situations. A novel algorithm model using Grey Error Theory [6] to estimate the measuring accuracy is also developed. The measurement result is also compared to the conventional method to determine total weights on the accuracy of the obtained values. The improvement by this method and the new algorithm model on the accuracy can be shown clearly.

## 2. Measurement Principle and Experiments

### 2.1 Measurement Principle

The detector of the weighing system is a road-weighbridge that is installed in the road, such that the surface of the road-weighbridge is just at the same level of the road. The road-weighbridge is nearly as long as the diameter of a tire.

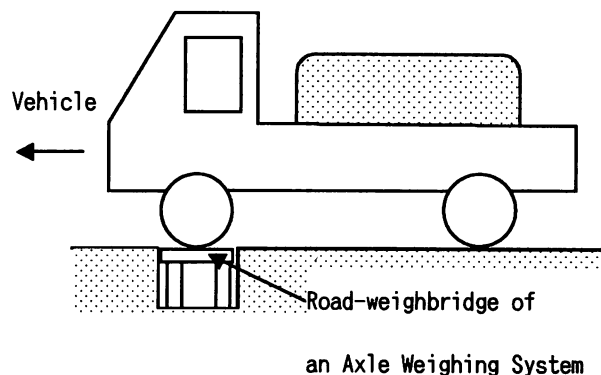


Fig. 1 A road-weighbridge of an axle weighing system

As shown in Fig.1, the axle weighing system measures each axle weight of a vehicle while it passes the road - weighbridge. The total weight of the vehicle could be estimated by using the whole signals that are obtained while the vehicle passes through the road-weighbridge.

The conventional calculating method in the axle weighing systems is called "Mean Value Method". By taking mean value of each segmented part of the signal obtained while the axle is completely on the road-weighbridge, each axle weight can thus be determined [7].

However this method does not take the vibration component into account, and thus the accuracy of the determined axle weights is inevitably low. We do not think it would be accepted for more strict regulation of the over-loaded vehicles in the future.

By doing carefully analysis for time behavior of the signal from the road-weighbridge especially the vibration component contained in the measurement process, we have made clear the cause of the vibrations. The dynamic equations of the motion model were given, and a novel estimation method for total weight of in-motion vehicles was set up [8].

### 2.2 Experiments

The method was applied to real data of cab-over-engine trucks with 2 axles and cab-over-engine trucks with 3 axles in many situations. The maximum authorized payload of the cab-over-engine truck with 2 axles and the cab-over-engine truck with 3 axles used in the experiments is 8,000kg and 10,000kg, respectively [8].

In this paper we only discuss the conditions of cab-over-engine truck with 3 axles, the maximum authorized payload of 10,000kg, and the over-loaded of 150% with a velocity of 10km/h. The measurements were conducted in different places and different times with different loads.

3. Grey Estimation for Measurement Uncertainty

The Grey Error Theory [6] is a new theory developed in recent years. It is especially used to solve the measurement issue, which the traditional Statistical Theory is not suitable.

Tab.1 Hokko West Station

Weight Value (kg)			
Method No.	Novel	Mean	True
1	24979.11	24542.44	25066.33
2	24505.09	24309.33	
3	24818.17	24527.40	
4	24826.70	24563.91	
5	24816.17	24566.41	
Average	24789.05	24501.90	
Error	-277.28	-564.43	
G.S.D.	141.98	96.29	
S.D.	173.03	108.84	

Tab.2 Takaishi Station

Weight Value (kg)			
Method No.	Novel	Mean	True
1	25962.59	26183.39	26123.69
2	26406.49	26701.49	
3	25933.19	26331.89	
4	26476.36	26812.83	
5	26081.29	26541.66	
Average	26171.98	26514.25	
Error	48.29	390.56	
G.S.D.	269.43	256.61	
S.D.	253.34	258.69	

Tab.3 Sakai Station

Weight Value (kg)			
Method No.	Novel	Mean	True
1	26871.20	27185.27	26615.69
2	26426.11	26593.33	
3	26349.53	26298.96	
4	26628.20	26224.44	
5	26562.46	26442.69	
Average	26567.50	26548.94	
Error	-48.19	-66.75	
G.S.D.	182.20	340.37	
S.D.	202.14	382.74	

Tab.4 Yanagihara East Station

Weight Value (kg)			
Method No.	Novel	Mean	True
1	25954.61	26171.29	26399.44
2	26038.80	26074.99	
3	25968.40	26348.40	
4	26004.10	26203.41	
5	25977.05	26140.90	
Average	25988.59	26187.79	
Error	-410.85	-211.64	
G.S.D.	32.86	88.09	
S.D.	33.38	101.53	

The measurement results in different places are listed in Tabs.1-4. The conventional “Mean Value Method” [7] is abbreviated by “Mean” and the novel method [8] is abbreviated by “Novel” respectively in the tables.

We use Grey Error Theory to calculate its Grey Standard Deviation[9] (abbreviated by “G.S.D.” in the table) . For comparison, the Normal Standard Deviation derived by Bessel Formula[10] is also listed in the table (abbreviated by “S.D.” in the table) .

From the tables we can see that, the data sample in each station is no more than 6. It is the typical less sample size measurement. In this case, we do not know its distribution from experience and it is also difficult for us to judge whether it obeys some typical statistical distributions or not. Therefore the Statistical Theory cannot be used here to calculate the standard deviation of the measurement.

#### 4. Discussions

From the above tables we can see that the error of the “Novel” method is less than that of the “Mean” one except Tab.4, which shows the result of the new method is close to the true value. We also observe that the standard deviation by Bessel Formula of the “Novel” method is less than that of the “Mean” one except Tab.1, which shows the deviation of the new method is small. The Grey Standard Deviation of the “Novel” method in Tab.1 and Tab.3 is a bit larger than that of the “Mean” one. As for Tab.2 and Tab.4 the case is quite different because the Grey Standard Deviation of the “Novel” method is much smaller than that of the “Mean” one.

We notice the results of the Grey Standard Deviation both for the “Novel” method and the “Mean” method in the tables are all smaller than the Bessel standard deviation except for the “Novel” method in Tab.4, which is a little different. This shows the standard deviation calculated by the Grey estimation method is more accurate than that of the Bessel method because it is quite difficult for us to judge the distribution type of the measured data under the conditions that the sample size is only 5, which is much smaller than the necessary qualifications.

#### 5. Conclusions

The novel method is based on the estimation model taking the vibration of in-motion vehicles into account and using the linear regression models. By taking advantage of the Grey estimation for measurement uncertainty, we could get the good results.

By comparing the novel method with the old one, we found both methods are suitable for the weight measurement in the in-motion vehicles. The novel method should be taken into account if the measurement accuracy is desired to be higher.

The Grey estimation method for measurement uncertainty is very useful in the case of small data sample, this point is already proved by many different measurement practices.

As for the abnormality and several exceptional cases of the results in the tables, it is necessary and very important for us to do some more research work in the future.

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