

An efficient system of compressed natural gas (CNG) secondary filling station based on reducing abnormal refilling behaviors

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Abstract. CNG secondary filling station is a critical infrastructure in CNG industry. By data mining, it is found that there are energy inefficient refilling behaviors with abnormal small volume, higher initial pressure, lower final pressure, or tiny change in pressure. Therefore, an energy efficient system of CNG secondary filling station is provided by reducing these abnormal inefficient actions in this article. The performance of the provided system is measured by analyzing the statics of these abnormal behaviors. It is found that if the abnormal inefficient refilling behaviors were avoided, the efficient system of CNG secondary filling station will be improved by no less than 12.937 percent.

1. Introduction

Natural gas consists mainly of methane. Compressed natural gas (CNG), used as a transportation fuel, is stored in high-pressure (20MPa in China) tanks on the vehicle. During the refilling process, CNG vehicles (CNGVs) connect to the high pressure reservoir tanks at refueling stations through compressed natural gas dispenser for vehicle. Because of its environmentally friendly and economic merits compared to traditional transportation fuel, such as gasoline and diesel, CNG used as an alternative to traditional transportation fuel has increased in the world in recent years. But the CNG filling stations as a critical infrastructure in CNG industry are not enough to meet the increasing demand. The drivers of CNGVs usually need to wait 2 or 3 hours to refill their cars ^[1-3]. There are many reasons lead to this results as the references ^[1] to ^[3] pointed. One of them is the inefficiency of the filling system.

In order to make the utilization of the secondary CNG filling station more efficient, in this article, the inefficient refilling behaviors of a secondary CNG filling station in Tianjin are analyzed by data mining methods, and an energy efficient system is provided to increasing the efficiency of the filling station. As far as we known, many researches about the efficiency of CNG filling station are either by mathematical modelling ^[4] or simulation ^[5,6]. In this study, empirical methods are adopted to provide a possible energy more efficient system. The empirical methods include outlier detection methods such as boxplot methods, kernel density estimated (KDE) methods and statics methods.

The paper is arranged as follows: In Sec. 2, the data and methods used in this research are introduced. The empirical analysis results are presented in Sec. 3. And the Sec. 4 conclude the paper.

2. Dataset and methods



2.1. Dataset

The dataset used in this research contains 254,841 records of a year refilling log collected from a secondary CNG filling station in Tianjin. Each log has 24 attributes. Only 4 attributes are used in this research because these variables describe occurring time, physical properties, such as volume, initial and final pressure of the on-board storage of CNGV, of refilling behaviors. The dataset start from January to December in 2014. Table 1 provides an overall description of this dataset.

Table 1 The first 10 records of the dataset

Index	Time	Volume	Initial Pressure	Final Pressure
1	1-1-2014 0:00	17.53	4.2	17.7
2	1-1-2014 0:01	13.53	7.2	18.6
3	1-1-2014 0:03	8.58	10.2	18.4
4	1-1-2014 0:05	14.47	6.4	18.3
5	1-1-2014 0:08	14.23	6.4	18.1
6	1-1-2014 0:11	14.75	6.3	18.5
7	1-1-2014 0:12	13.65	7.2	18.3
8	1-1-2014 0:14	8.63	8.9	17.6
9	1-1-2014 0:15	21.02	2.1	18.2
10	1-1-2014 0:17	16.05	5.1	17.6

The “Index” means the order of the refilling behavior in this dataset. The attribute “Time” indicates when the refilling behavior happened. “Volume” is the amount of CNG filled into the on-board storage in the refilling behavior measured by mass flow meter of CNG dispenser under standard state, the “Initial Pressure” and “Final Pressure” provide the value of pressure of the on-board storage before and after the refilling behavior.

In addition, two derived variables are used in this research. One is the time interval between the neighboring refilling behaviors of each dispenser gun, which is described as dt . Another derived variable is the change in pressure of on-board storage by the refilling behavior, which is described as dp and is defined as

$$dp = pf - pi.$$

2.2. Methods

As a common sense, a refilling behavior with small volume, higher initial pressure of the on-board storage, lower final pressure of the on-board storage, or small change in pressure of the on-board storage should be considered as an inefficient refilling behavior. However, there is no standard values for these attributes to determine what value is small, higher, or lower enough. Therefore, some methods have to be used to computer these critical values. The methods used in this research include boxplot method ^[7] and kernel density estimated (KDE) method ^[8], both of which are based on single attribute. Additionally, scatter matrix plot ^[9], a visualization method is adopted in this paper. Finally, to empirically study the effect of the energy efficient system by avoid abnormal refilling behaviors, the statistics ^[10] of dt is calculated.

3. Empirical analysis results

Based on attributes of volume, initial pressure of on-board storage, final pressure of on-board storage, and derived variable of change in pressure, their critical values are found by boxplot. Figure 1 shows the results of boxplot and KDE analysis. The upper dotdashed red line represents the upper critical value, which is 23.295, based on boxplot method. And the lower dashed red line represents the lower critical value, which is 1.395. The gray curves in the central of Figure 1 is the density distribution by KDE. The gray dashed lines represent the quartiles.

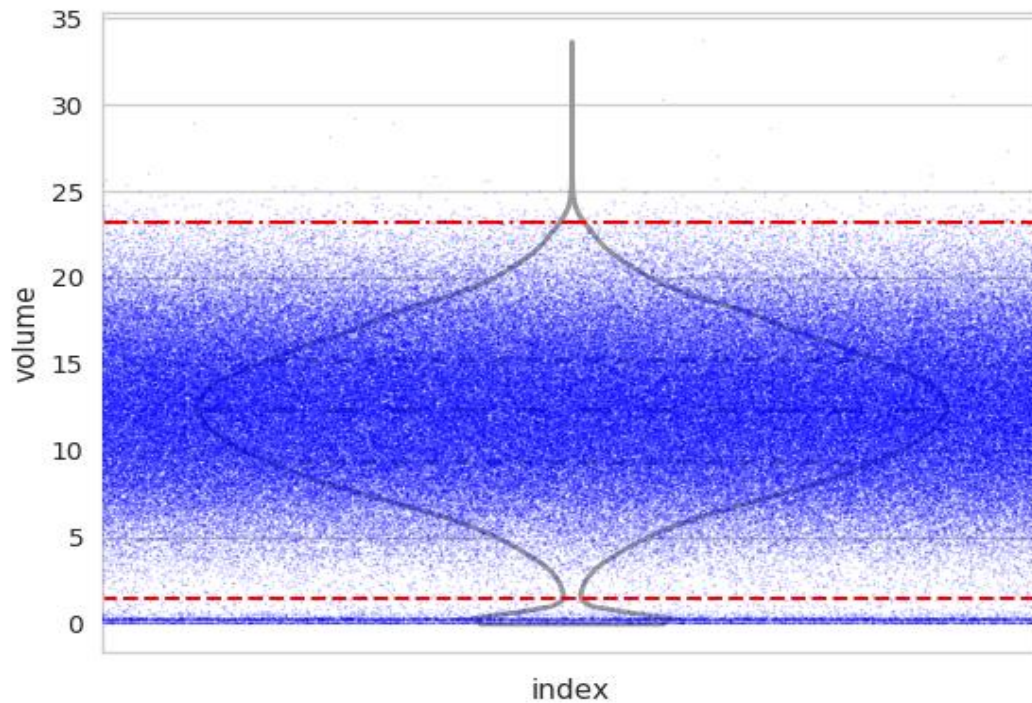


Figure 1. Scatter plot and violinplot of volume (color online).

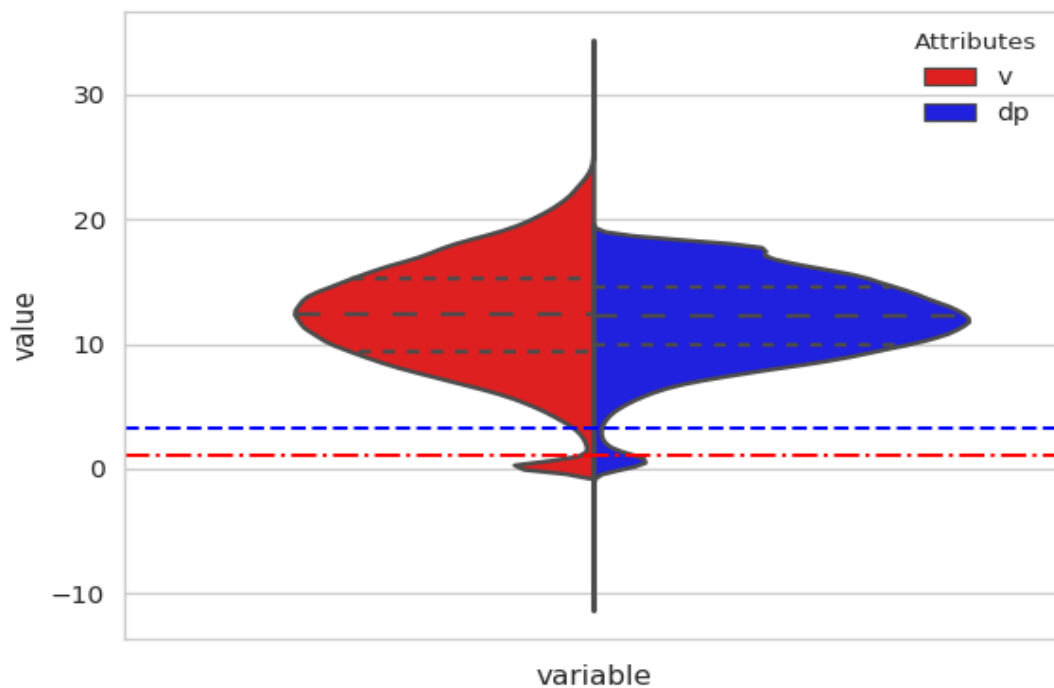


Figure 2. Violinplot of volume (v) and change in pressure (dp)(color online).

From Figure 1, by KDE method, volume has bimodal distribution. There are some refilling behaviors with volume less than 1.020 Nm^3 , which is detected by boxplot method. It is reasonable to see these refilling behaviors as outliers. By boxplot method, there are abnormal behaviors with volume larger than 23.97. But from the perspective of energy efficiency, these actions are appreciated. Therefore, only behaviors with less volume are studied in this article.

Because of small volume usually corresponds to small change in pressure, both of volume and change in pressure of each refilling action are plotted in Figure 2. This figure contains only violinplot except of critical abnormal values of volume and change in pressure. In Figure 2, the red dotted line represents the critical abnormal value, which is 1.020 Nm^3 , and the blue dashed line is the critical abnormal value of change in pressure with value of 3.20 MPa. As expected, both the volume and change in pressure have bimodal distribution, and both have abnormal behaviors with small values, which are reasonably considered as energy inefficient.

From the view of initial pressure of on-board storage and final pressure of no-board storage, an efficient refilling behavior has both lower initial pressure and higher final pressure. Otherwise, a refilling action with higher initial pressure or lower final pressure should be considered as inefficient. Thus, the violinplot of initial pressure and final pressure of on-board storage is plotted in Figure 3. As shown in Figure 3, refilling behaviors with initial pressure larger than 14.967 MPa or final pressure less than 16.900 MPa are considered as abnormal actions by boxplot method. And these outliers are inefficient behaviors yet.

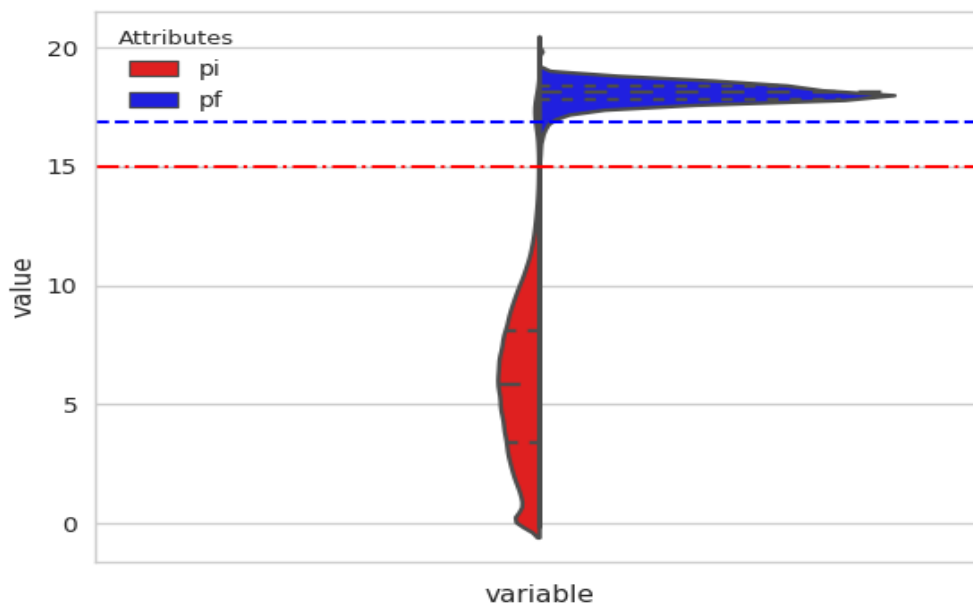


Figure 3. Violinplot of initial pressure (pi) and final pressure (pf)(color online).

4. Discussions and conclusion

4.1. Discussions

Based on boxplot and KDE methods, the energy inefficient refilling behaviors are studied. To improve the efficiency of CNG secondary filling station, one way is to avoid these inefficient actions. Table 2 lists the total time of these abnormal behaviors. In each cell, the number in parenthesis is the total time of abnormal behaviors under the condition of both its attributes on its column and row. And the number of each cell without parenthesis is its number of abnormal actions, which showing that volume and final pressure are two more important attributes to detect abnormal behaviors.

Table 2. Time interval statistics of energy inefficient refilling behaviors.

	Volume	Change in pressure	Initial Pressure	Final pressure
Volume	6533(57005)	6041(55111)	5548(25841)	706(30864)
Change in pressure	6041(55111)	7117(102290)	6222(30569)	1004(72270)
Initial pressure	5548(25841)	6222(30569)	6291(30875)	184(1224)
Final pressure	706(30864)	1004(72270)	184(1224)	5983(245856)

4.2. Conclusion

From Table 2 and the abnormal behaviors detection analysis, it is concluded that one way to improve the energy efficiency of the CNG secondary filling station is to avoid their abnormal refilling behaviors. Since volume and final pressure are more important, the abnormal behaviors detected by volume and final pressure are deserved paying more attention. If these abnormal actions are avoided, the CNG secondary station would reserve more than 271997 minutes (which is calculated by $57005+245856-30864$) effective refilling time, or 188.86 effective refilling day per year (The total effective refilling day per year is 4 years because there are four dispenser guns in this CNG secondary filling station). In other words, this efficient improvement is about 12.937%. But how to avoid these abnormal behavior is needed to be further studied.

Acknowledgments

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