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ANALYSIS OF MANUAL INVENTORY RECONCILIATION

EXECUTIVE SUMMARY

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Richard F. Eilbert
Entropy Limited
Lincoln, MA

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Richard F. Eilbert
Entropy Limited
Lincoln, MA

EXECUTIVE SUMMARY

Objectives

This report documents the findings on manual inventory reconciliation as practiced at gasoline service stations. The objectives are 1) to identify factors affecting daily recordkeeping accuracy, and 2) to evaluate the leak detection capability of proposed regulatory standards. Leak detection capability is assessed by numerically modifying actual inventory data through computerized simulations of various leak rates.

Data Base Selection

The study is based on 586 underground storage tanks at 188 facilities nationwide. Data are comprised of 20,036 measurements of daily inventory. Geographic coverage spans 34 states. This is, to our knowledge, the largest data base on manual inventory assembled to date.

Entropy Limited has performed statistical inventory analysis for many thousands of underground storage tanks. A sampling of these has been selected to form this project's data base. Statistical inventory analysis greatly improves the leak detection capability of inventory recordkeeping, but requires advanced computerized methods available from firms providing such services. This project focuses on manual inventory reconciliation as practiced by dealers in the retail gasoline trade.

Facilities and recordkeeping periods were selected on the basis of geographical and seasonal representativeness. It is not known which, if any, of the tank/piping systems might have actually been leaking. Industry estimates suggest that most of the systems, perhaps 98 to 99%, were tight.

When the sample was drawn, recordkeeping accuracy was not considered and, in fact, was not yet known. The recordkeeping in the sample is expected to be of somewhat higher caliber than that maintained in the retail gasoline trade at large. Reasons for this include: 1) clients submitting records are ususally trying to meet regulatory or insurance requirements and thus are motivated to perform recordkeeping more conscienciously, 2) obviously deficient inventory records are returned without analysis under Entropy Limited's Quality Assurance protocols, and 3) arithmetical blunders have been eliminated by computerizing the bookkeeping procedure. Entropy Limited's Quality Assurance protocols also include checks to reject artificially contrived inventory data.

Data Base Characteristics

Within the data base, 95% of the tanks are used to store gasoline or diesel products. Geographical coverage of the nation's major regions is consistent with general motor fuel consumption patterns with the exception that the Rocky Mountain region is under-represented.

Inventory record length for the tanks consists on average of 34 reconciliations covering a 43 day period. This reflects the fact that statistical inventory analysis normally is based on 30 submitted measurements, not including days on which the station is closed. The averaged tank size is 7,277 gallons and monthly throughput averages 16,258 gallons/month. As a whole, the net loss of product exhibited in the data base is quite small, averaging 0.40 gal/day or 0.10% of throughput. Individual tanks, on the other hand, are characterized by much larger gains or losses of product.

Factors Affecting Daily Inventory Reconciliation

The accuracy with which inventory is reconciled on a particular day is quantified as the "daily discrepancy." This discrepancy is defined as the measured change in stored volume plus dispensed sales minus delivery receipts. Overages exceeding 90 gallons occur 5% of the time. Similarly, underages of 90 gallons or more occur with 5% frequency. Daily losses and gains exceeding 220 gallons each occur only 1% of the time. Daily discrepancies in the range of -20 to +20 gallons are more typical, and account for 50% of the observations.

The capabilities of manual inventory reconciliation as a leak detection method are, to an extent, limited by the tank operator's ability to obtain accurate daily reconciliation. In the retail trade, it is widely recognized that some of the day-to-day variability cancels out when looking at reconciliations over a longer time frame, such as a month. The reason for this cancellation is that bookkeeping inaccuracies on one day will be compensated on subsequent days, assuming no physical loss of product occurs. In assessing manual inventory reconciliation, it is important to look at performance on daily, monthly and even longer time scales.

A number of factors impact the accuracy of daily inventory reconciliation. These are studied by examining the standard deviation in the daily discrepancy. This standard deviation is 39 gallons for the entire data set, excluding outliers beyond 125 gallons (less than 6% of the data). Factors impacting the daily reconciliation accuracy include throughput, delivery, tank size, stick reading accuracy, product and season or month.

STRONG DEPENDENCIES

- Product throughput. A strong dependency of daily discrepancies on throughput exists. This occurs because discrepancies caused by dispensing meter error, thermal changes in product volume, vapor loss and conversion chart inaccuracy are proportional to the volume of throughput. Also, high throughput stations receive more frequent product deliveries, introducing additional cause for discrepancy.

- Occurrence of product delivery. Higher discrepancies are exhibited on delivery days than on non-delivery days. When analyzed with outlier rejection, the standard deviation is only moderately higher for delivery days than non-delivery days (44 versus 37 gallons). However, the percentage of outliers on delivery days is unusually high, 10%, versus 5% on non-delivery days. Delivery days comprise 22% of the data base.

- Tank size. The strong dependence of daily discrepancies on tank size is partially due to its significant intercorrelation with throughput

(r=0.62). This occurs because tank owners tend to use large tanks for products with high activity. Tank size directly affects discrepancies through scale error, that is, a 1/4" error in dipstick reading causes a proprotionally larger inventory discrepancy for larger sized tanks.

MODERATE DEPENDENCIES

- Stick reading accuracy. Stick reading accuracy is 1/8", 1/4", 1/2" or 1". The accuracy of the stick readings is known for 87% of the tank data. Daily discrepancies are reduced with finer stick reading accuracy, down to and including 1/8". However, the reduction in discrepancies in going from 1/4" to 1/8" is only partially attributable to the finer measurement accuracy. A major portion of the reduction is due to other factors such as a more consciencious attitude of operators seeking high measurement accuracy and their reliance on conversion charts precalibrated in 1/8" increments.

WEAK DEPENDENCIES

- Product. Daily discrepancies have only minor dependency on the type of product contained in the tank, with slightly higher discrepancies exhibited for unleaded than for leaded gasoline. This increased discrepancy is a result of the generally higher throughput of the unleaded product.

- Month of year. There is no clearcut trend or annual cycle in the magnitude of daily discrepancies. This contrasts with the generally held belief that accurate inventory reconciliation is more difficult during the winter months.

The accuracy of daily reconciliation discussed above characterizes the size of typical daily overages or shortages. On average, positive and negative discrepancies will tend to cancel so that the expected daily reconciliation is close to zero. In fact, the data base exhibits an expected discrepancy of -0.50 gallons for daily reconciliations, which is but a small fraction of the 39 gallon standard deviation characterizing daily reconciliation accuracy. Factors affecting daily discrepancies were assessed for biases that would shift the expected reconciliation away from its -0.50 gallon average.

A detectable bias exists for high throughput tanks, namely, those with over 20,000 gallons of monthly throughput. This bias is well explained by vapor loss. A bias is also evidenced within the annual cycle. This becomes more apparent when the data are restricted to the northern states, which experience larger seasonal temperature swings. Loss of product occurs in May through August, while the rest of the year experiences gains which peak in November/December. This annual cycle is well recognized within the retail trade, summer losses being known as thermal shrinkage. Within a specific season, thermally induced biases in inventory reconciliation are expected to vary proportionally with product throughput.

Evaluation of Proposed Regulatory Standards

A number of regulatory standards have been suggested to enable inventory reconciliation to function as a leak detection method. Two of the most familiar are the "0.5% of monthly throughput" rule recommended by the API and

the "action number" approach developed by the EPA. We evaluated the performance of these rules applied on a monthly basis. Through computerized calculations, constant, artificial leak rates from 2 to 50 gal/day were imposed on the inventory data base to simulate tank leakage. In this way, the sensitivity of the above rules in detecting leakage can be estimated.

Findings are expressed in terms of the false alarm (FA) rate (i.e., the frequency with which a standard indicates a leak when none exists) and the leak rate, R_{95}, at which a standard would detect the leak 95% of the time. The findings presume, in accord with industry and insurance company estimates, that only a very small fraction of the data-base tanks are actually leaking. This assumption is born out by the high degree of symmetry between positive and negative daily discrepancies within the data base. If a significant fraction of the data base tanks were leaking, an asymmetry toward negative discrepancies would occur. The analysis concludes the following:

- o 0.5% of monthly throughput rule. The false alarm rate for product loss occurs with frequency FA = 30%. Product gains exceeding 0.5% of throughtput occur 27% of the time. The high FA rate makes this rule unworkable without modification.

- o Action number approach. For 30 days of measurement, action is triggered if losses exist on 20 or more days. This occurs with false alarm rate FA = 4.6%. A 95% chance of detection occurs at a leak rate of R_{95} = 2.0 gal/hr. This rate is considered to be rather high for leak detection purposes.

A class of standards expressable as a percentage of monthly throughput plus a constant term was examined for their leak detection performance. Significant improvement in leak detection capability is demonstrated with such rules. Leak detection efficiency at a fixed 5% FA rate is optimized by selecting the criterion to be 150 gallons plus 0.8% of throughput. Specifically:

- o 150 gallons + 0.8% of monthly throughput rule. A 5% FA rate is expected and 95% chance of leak detection occurs at leak rate, R_{95} = 0.9 gal/hr. According to our data, this rule has more than twice the sensitivity of the action number approach.

This standard is somewhat more efficient than the "123 gallons plus 1.23% of monthly throughput" rule reported in a preliminary study, for which R_{95} = 1.5 gal/hr at a 5% FA rate. A convenient standard that is nearly optimal is "130 gallons plus 1.0% of monthly throughput," for which R_{95} = 1.1 gal/hr at a 5% FA rate.

The validity of such rules is governed by the data upon which they are based. In particular, the rules are applicable to underground tanks in the retail gasoline sector of capacities in the range 500 to 50,000 gallons with throughputs in the range of 1,000 to 100,000 gallons per month.

Daily Inventory Reconciliation Standards

Imposing daily inventory standards for leak detection would be a futile exercise. Employing, for example, a 90 gallon loss rule to achieve FA = 5% results in a sensitivity of R_{95} = 5.9 gal/hr. Of course, an FA of 5% on a daily basis creates an 80% chance for one or more false alarms per month.

Some standard governing daily reconciliation is worthwhile to prevent procedural and arithmetical blunders in bookkeeping. For tanks of capacity below 20,000 gallons, 50 gallons plus 1% of tank size defines a reasonable maximum allowable daily discrepancy. About 95% compliance rate with this rule is exhibited in the data base. Conscienciously practiced inventory reconciliation should be routinely capable of meeting this upper limit on daily product discrepancy.

Improving Leak Detection Capabilities of Inventory Reconciliation

Higher leak detection sensitivities result by extending the baseline period for the inventory reconciliation beyond one month. Since the data base contains few instances of periods exceeding 45 days, the performance of longer time-period rules has to be extrapolated based on theoretical models. Analysis shows the following to be achievable for a 3-month rule:

- o 300 gallons plus 0.5% of 3-month throughput rule. The false alarm rate is expected to be FA = 1%. This is one-fifth of the previous FA rates and low enough to be practicable. The leak rate detectable with 95% confidence is expected to be R_{95} = 0.4 gal/hr. If the extrapolation is valid, the sensitivity of the optimal one-month rule can be more than doubled.

In theory, leak detection capability continues to improve with increasing baseline period of inventory observation. In practice, factors such as meter error, vapor loss, thermal shrinkage of product and other systematic errors ultimately limit the leak detection capability of manual inventory reconciliation. Statistical inventory analysis programs account for such factors and make more intensive use of the daily inventory records. They can achieve sensitivities of about 0.1 gal/hr on 30-day analyses, representing the state-of-the-art capability for leak detection through inventory reconciliation.

Conclusion

Analysis of manual inventory reconciliation data as practiced in the retail gasoline trade indicates that leak rates of 0.9 gal/hr are detectable with high confidence over a one month time period. The major factors impacting the operator's ability to achieve accurate daily inventory balance are product throughput, tank size, product delivery, and the precision of dipstick reading. Bias in inventory reconciliation can be induced by vapor loss, thermal product shrinkage, meter error and other causes. Improved leak detection capability is possible by using longer baseline periods for reconciliation and by using computerized statistical inventory analysis.