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REPURPOSING THE VESSEL EXPERIENCE FACTOR AS A STATISTICAL PROCESS CONTROL TOOL FOR TANKER CARGO MEASUREMENT

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Abstract: Accurate reconciliation of cargo quantities measured on board a tanker with those declared by shore terminals is central to reliable tanker operations and to the prevention of commercial disputes. The Vessel Experience Factor (VEF), provides a historical, vessel-specific relationship between shipboard and shore measurements and is traditionally used as a cargo-reconciliation and loss-control tool. This paper investigates whether the same historical VEF population can additionally support the statistical quality control of the ship/shore measurement process itself. A case study was carried out using operational data from 23 consecutive loading operations of a medium-range product/chemical tanker, covering nine cargo grades and fifteen terminals. For each voyage, the Ship/Shore Ratio was computed and compared with unity, with the vessel's historical VEF and with a ±0.3% tolerance band reinterpreted as Shewhart-type control limits. Descriptive statistics, a normality check and an individuals control chart were used to assess the stability of the measurement process and to identify voyages departing from the vessel's established behaviour. The historical VEF was 0.99947 (n = 20 qualified voyages), all 23 ratios remained inside the ±0.3% band, and a five-voyage window (voyages 241-246) revealed two short downward runs separated by a partial recovery - a pattern invisible to a simple per-voyage tolerance check. The results show that VEF data, already collected for commercial reasons, can be repurposed at no additional cost into a vessel-specific quality-control indicator that complements, rather than replaces, conventional cargo reconciliation.

Keywords: Cargo reconciliation; Quality control; Ship/Shore ratio; Statistical process control; Tanker cargo measurement; Vessel Experience Factor.

1. INTRODUCTION

Seaborne trade continues to move the overwhelming majority of the world's liquid energy cargoes, and product and crude oil tankers remain the backbone of this logistical chain. On every laden voyage, the quantity of cargo transferred between a shore terminal and a vessel is determined twice, independently, by two measurement systems that rarely agree perfectly: the terminal's tank gauges or mass-flow meters, and the vessel's own calibrated tank tables read through Ullage, Temperature and Interface (UTI) probes or fixed radar gauges [2],[3]. The resulting “ship figures” and “shore figures” are reconciled at the close of every cargo operation, and the discrepancy between them - however small - is one of the most frequent triggers of commercial disputes between shipowners, charterers and terminal operators.

The industry's principal instrument for managing this discrepancy is the Vessel Experience Factor (VEF), formalised by the American Petroleum Institute in the Manual of Petroleum Measurement Standards (MPMS), Chapter 17.9 / Energy Institute HM 49 [1]. VEF condenses the historical ship/shore performance of an individual vessel, typically over its last 20 or more qualifying voyages, into a single correction coefficient applied to future Bills of Lading to separate the vessel's own systematic bias from genuine cargo loss. In this original conception, VEF answers a commercial question - how much cargo is really missing - rather than an engineering one: is the measurement process itself in a state of statistical control.

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This paper argues that the second question is equally important, and that the historical VEF data set already collected by every tanker for commercial reasons can be repurposed, at no additional operational cost, into a quality-control instrument for the ship/shore measurement process. Framed in the language of statistical process control (SPC), the vessel-specific VEF becomes a process centre line, its ±0.3% commercial tolerance becomes a pair of control limits, and every new voyage becomes an individual observation to be plotted, monitored for drift and investigated when it strays. This turns cargo reconciliation - traditionally a retrospective, voyage-by-voyage commercial exercise - into a prospective, statistically grounded quality-control routine that a Chief Officer can run from the cargo office with data already generated for other purposes.

The remainder of the paper is organised as follows. Section 2 reviews the regulatory and theoretical background of tanker cargo measurement and the VEF methodology, and situates the proposed approach within the wider statistical process control literature. Section 3 describes the case-study vessel, the operational data set and the statistical methods applied. Section 4 reports the results for 23 consecutive loading operations, including an individuals control chart and a distributional assessment. Section 5 discusses the practical and methodological implications, and Section 6 concludes with recommendations for onboard practice and directions for further research. Related tanker-safety and tanker-efficiency studies have previously been reported in this journal, addressing port-state-control deficiency analysis [10] and energy-efficiency trends on large crude carriers [11], underscoring the continued relevance of tanker-specific operational research.

2. REGULATORY AND THEORETICAL BACKGROUND

2.1 Cargo measurement and custody transfer on tank vessels

On a product or crude oil tanker, the quantity of liquid cargo loaded or discharged is never weighed directly; it is reconstructed from a sequence of volumetric and physical measurements standardised by the American Petroleum Institute through the Manual of Petroleum Measurement Standards (MPMS) and by the American Society for Testing and Materials [3],[4], and operationally framed by the International Safety Guide for Oil Tankers and Terminals (ISGOTT) [2]. For each cargo tank, a UTI probe or fixed radar gauge yields the observed ullage, corrected for trim and list to obtain the Total Observed Volume (TOV) through the ship's calibration tables. Free water is subtracted to obtain the Gross Observed Volume (GOV), which is converted to the Gross Standard Volume (GSV) at the reference temperature of 15°C using the Volume Correction Factor obtained from the ASTM tables on the basis of density and observed temperature [4]. The GSV is finally converted into metric tons in air, the unit used commercially, through the standard air-buoyancy correction. Every step of this chain - the Ullage Report, the On-Board-Quantity and Remaining-On-Board surveys and the Bill of Lading - is retained on board as part of the Oil Record Book, Part II, required under MARPOL 73/78, Annex I [5], and forms the documentary basis on which cargo disputes are ultimately settled.

2.2 The Vessel Experience Factor as a loss-control instrument

Because the ship's tanks are calibrated by the shipyard under idealised conditions, while the vessel operates under continuously varying trim, list, structural deflection and sediment loading, a small, largely constant bias between ship and shore figures is expected even when both measurement systems function correctly. API MPMS Chapter 17.9 / EI HM 49 formalises the Vessel Experience Factor as the tool that isolates this vessel-specific bias from genuine cargo loss [1]. VEF is defined as the ratio of the cumulative ship-measured volume to the cumulative shore-measured (Bill of Lading) volume over the vessel's last minimum of 20 qualifying voyages carrying similar cargo grades:

$$\mathrm{VEF} = \frac{\sum_{i=1}^{n} V_{\mathrm{ship},i}}{\sum_{i=1}^{n} V_{\mathrm{shore},i}} \tag{1}$$

A voyage qualifies for inclusion in this historical population only if it is not a part cargo (loaded below 75% of tank capacity), is not a ship-to-ship (STS) transfer, and its individual Ship/Shore Ratio does not fall outside a control band of approximately ±0.3% around the vessel's running average [1]. For any subsequent voyage, the Ship/Shore Ratio is computed as

$$\text{Ship/Shore Ratio} = \frac{\text{Ship TCV}}{\text{Shore B/L TCV}} \tag{2}$$

where Ship TCV is the Total Calculated Volume determined on board immediately after loading (or

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before discharge) and Shore B/L TCV is the corresponding volume declared on the Bill of Lading. When the current voyage's ratio, once corrected by the vessel's historical VEF, still departs from unity by more than the contractually agreed tolerance - typically 0.3% under a standard Charter Party - the Chief Officer is obliged to issue a Letter of Protest to preserve the owner's position against a subsequent cargo-shortage claim.

2.3 From loss control to statistical quality control

Read purely as a loss-control ratio, VEF answers a single, retrospective, per-voyage question. Read as a time-ordered sequence, however, the same 20 or more historical Ship/Shore ratios are formally indistinguishable from the individual measurements plotted on a Shewhart control chart, the foundational SPC tool introduced by Shewhart [6] and developed into its modern form by Montgomery [7]: a centre line (the process average, here the historical VEF), upper and lower control limits (here the ±0.3% commercial tolerance) and a sequence of individual observations screened for out-of-control points, run patterns and gradual drift. This reinterpretation is not merely semantic. A control-chart view distinguishes between situations that a raw voyage-by-voyage comparison against unity cannot: ordinary common-cause variation around the vessel's own baseline; an assignable-cause signal at a single voyage; and a sustained, unidirectional drift across several consecutive voyages, the classical SPC signature of a slowly developing measurement fault rather than of a single erroneous reading.

Related work has approached the reliability of tanker cargo custody transfer from complementary angles. Meškuotienė et al. [9] analysed the metrological uncertainty of liquid-level gauging in cylindrical storage tanks, and Senol [8] modelled the human-factor contribution to chemical-cargo shortage incidents using fuzzy fault-tree analysis. To the authors' knowledge, however, the historical VEF population itself has not previously been analysed as a control-chart data set for onboard quality assurance, which is the specific contribution of the present study, building on prior operational case analysis conducted by the lead author during his sea-going assignment.

3. MATERIALS AND METHODS

3.1 Case-study vessel and data set

The empirical analysis uses operational cargo-measurement data collected on board a medium-range (MR) product/chemical tanker of approximately 40,000 DWT, compiled by the lead author during a six-month sea-going assignment as Second Officer. The data set comprises 23 consecutive laden voyages (internal voyage numbers 232 to 254), spanning loading operations at fifteen terminals in the Mediterranean, Black Sea, North Sea, Atlantic and Red Sea areas and covering nine clean-petroleum-product grades (unleaded gasoline, Jet A-1, ultra-low-sulphur diesel, gas oil, naphtha and reformate/gasoline blends). For every voyage, the ship-measured Total Calculated Volume and the corresponding Bill-of-Lading volume were extracted from the vessel's Ullage Reports and cargo documents and centralised in the vessel's onboard VEF record.

3.2 Variables and eligibility screening

For each voyage, the Ship/Shore Ratio and the percentage difference , 100 × (Ship TCV−Shore TCV) / Shore TCV, were computed. Voyages were flagged as qualified or excluded from the VEF calculation following the eligibility criteria of API MPMS 17.9 [1]: three voyages (nos. 242, 243 and 250) were STS transfers and were excluded, leaving n = 20 qualified voyages for the calculation of the vessel's historical VEF. All 23 voyages, including the three excluded ones, were retained for the descriptive and distributional analysis, since their measurement behaviour remains informative about the operational envelope of the ship/shore comparison even though it is not used to define the vessel's baseline.

3.3 Statistical analysis

The historical VEF was computed according to Eq. (1) over the 20 qualified voyages, and the corresponding ±0.3% control band was established around the aggregate ratio computed over all 23 voyages, consistent with the vessel's own onboard practice. The 23 individual Ship/Shore ratios were then plotted, in chronological order, as an individuals (Shewhart X) control chart against this centre line and control limits, and screened for points outside the ±0.3% band, for the most extreme voyages, and for runs of consecutive same-direction departures indicative of drift. Descriptive statistics of the percentage difference were computed separately for the full sample (n = 23) and the qualified sample (n = 20), and the normality of the qualified sample was assessed with the Shapiro-Wilk test, a

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standard precondition check before treating a small sample as consistent with the Gaussian assumptions implicit in classical Shewhart limits [7].

4. RESULTS

4.1 Data set and Ship/Shore ratio

Table 1 summarizes the ship-measured Total Calculated Volume, the Bill-of-Lading volume declared by the shore terminal, the resulting Ship/Shore ratio and the API MPMS 17.9 qualification status for each of the 23 voyages analysed, together with the totals used in the aggregate VEF calculation of Eq. (1).

Table 1. Ship/Shore cargo reconciliation data from the case-study vessel - 23 consecutive loading operations

No.	Voy.	Product	Load port	Ship TCV (m³)	Shore B/L TCV (m³)	Ship/Shore ratio	Diff. (%)	Qual.
1	232	Unleaded Gasoline	Midia	32,728.462	32,755.180	0.99918	-0.082	Yes
2	233	Gasoline 95 RON	Bourgas	40,109.140	40,146.298	0.99907	-0.093	Yes
3	234	Unleaded Gasoline	Midia	32,051.080	32,063.503	0.99961	-0.039	Yes
4	235	Gas Oil 10 ppm	Sidi Kerir	39,866.990	39,902.387	0.99911	-0.089	Yes
5	236	ULSD 10 ppm	El Dekheila	37,478.605	37,495.010	0.99956	-0.044	Yes
6	237	Unleaded Gasoline	Bourgas	30,029.018	30,016.572	1.00041	+0.041	Yes
7	238	Unleaded Gasoline	Aspropyrgos	26,920.517	26,940.794	0.99925	-0.075	Yes
8	239	Unleaded Gasoline 95	Thessaloniki	32,930.169	32,915.065	1.00046	+0.046	Yes
9	240	ULSD 10 ppm	Sidi Kerir	30,670.872	30,723.675	0.99828	-0.172	Yes
10	241	ULSD 10 ppm	Sidi Kerir	32,485.938	32,493.192	0.99978	-0.022	Yes
11	242	JET A1	STS OPL Ceuta	26,420.864	26,431.635	0.99959	-0.041	No
12	243	ULSD 10 ppm	STS Gibraltar	34,892.759	34,931.158	0.99890	-0.110	No
13	244	Naphtha	Bilbao	31,583.681	31,603.260	0.99938	-0.062	Yes
14	245	ULSD 10 ppm	Antwerp	32,908.125	32,924.124	0.99951	-0.049	Yes
15	246	Gasoline 98RON/Eurobob	Amsterdam	25,381.375	25,443.972	0.99754	-0.246	Yes
16	247	Reformate/Gasoline C7	Lavera	30,423.045	30,413.835	1.00030	+0.030	Yes
17	248	Unleaded Gasoline 95 RON	Antwerp	32,613.266	32,635.530	0.99932	-0.068	Yes
18	249	Gasoline	Sarroch	32,484.214	32,411.372	1.00225	+0.225	Yes
19	250	ULSD 10 ppm	STS OPL Limassol	27,944.248	27,933.535	1.00038	+0.038	No
20	251	Unleaded Gasoline 95 RON	Vassiliko	29,908.892	29,932.193	0.99922	-0.078	Yes
21	252	Unleaded Gasoline 95 RON	Agioi Theodoroi	44,544.945	44,599.288	0.99878	-0.122	Yes
22	253	JET A1	Aliaga	41,661.189	41,646.448	1.00035	+0.035	Yes
23	254	Unleaded Gasoline 95 RON	Antwerp	44,742.369	44,820.465	0.99826	-0.174	Yes
		TOTAL (n=23)		**770,779.763**	**771,178.491**	**0.99948**	**-0.052**	-
		Qualified VEF (n=20, Eq. 1)		681,521.892	681,882.163	**0.99947**	-	-

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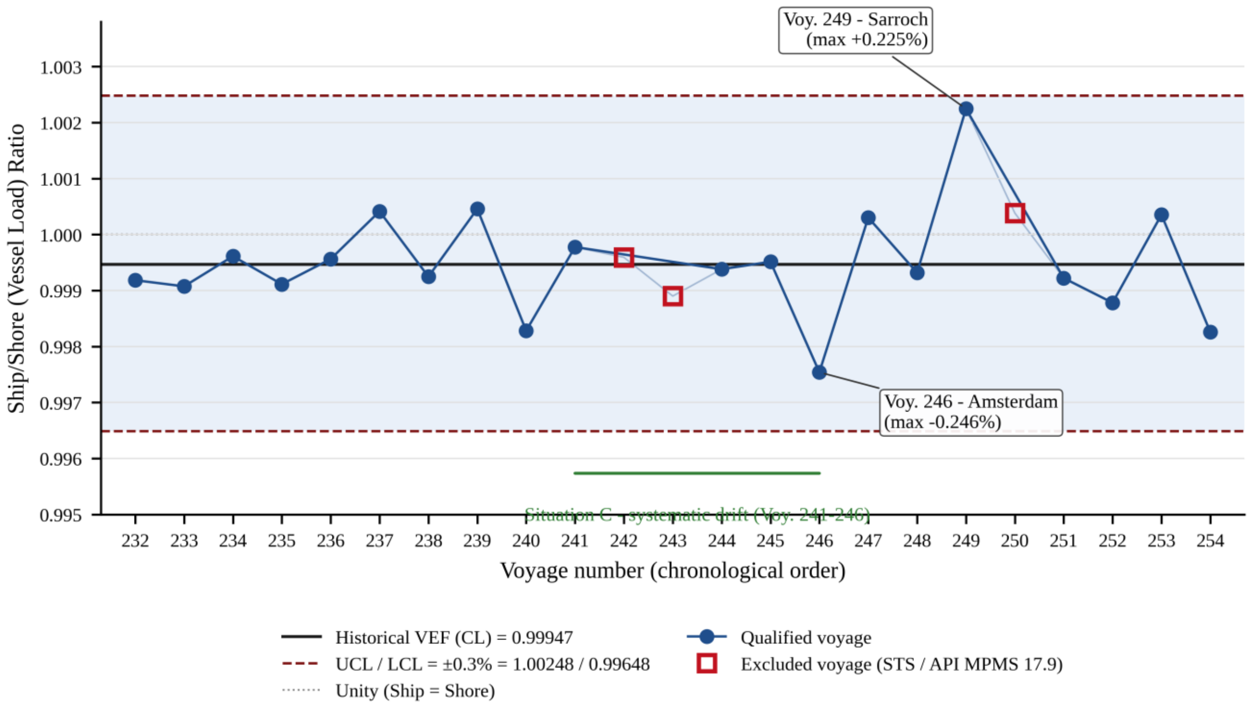

Figure 1 Individuals control chart of the Ship/Shore ratio for 23 consecutive loading operations of the case-study vessel, with centre line at the qualified VEF (0.99947) and ±0.3% control limits [1]

4.2 Vessel Experience Factor and process center line

Over the 20 qualified voyages, the aggregate historical VEF was 0.99947 (ΣShip TCV = 681,521.892 m³; ΣShore TCV = 681,882.163 m³), i.e. the vessel measured on average about 0.053% less cargo than declared by the shore terminals - a bias well inside the ±0.3% commercial tolerance and consistent with the small, structurally driven under-reading typically expected from an MR product tanker of this tank geometry. Over all 23 voyages the aggregate ratio was 0.99948, confirming that the three STS voyages excluded on eligibility grounds did not materially bias the vessel's overall measurement behaviour; they were excluded for procedural, not statistical, reasons. The mean of the 20 qualified percentage differences was -0.052% (s = 0.099%), closely matching the full-sample mean of -0.050% (s = 0.095%, n = 23), and a Shapiro-Wilk test on the qualified sample did not reject normality (W = 0.933, p = 0.178), supporting the use of Gaussian-based control limits for this data set.

4.3 Control-chart analysis

Figure 1 plots the 23 Ship/Shore ratios in chronological order against the qualified VEF centre line and the ±0.3% control band. All 23 voyages fall inside the band. Voyage 249 (Sarroch, +0.225%) came closest to the upper control limit, a departure attributed in the source record to line-pack effects and transient micro-foaming at high loading rates; voyage 246 (Amsterdam, -0.246%) recorded the largest negative departure, about 0.1 percentage points inside the lower limit, associated with the flashing of light hydrocarbon fractions from a gasoline/Eurobob blend measured by shore mass-flow meters. Neither point constitutes a formal out-of-control signal, but both fall in the region that API MPMS 17.9 identifies as warranting re-verification of ullage, temperature, density and trim/list corrections before the Bill of Lading is signed [1].

A closer inspection of voyages 241-246 - flagged in the source operational record as a single continuous downward trend - shows a more nuanced pattern: a three-voyage downward run from voyage 241 to voyage 243 (0.99978 → 0.99959 → 0.99890), a two-voyage partial recovery to voyage 245 (0.99938 → 0.99951), and a further sharp drop at voyage 246 (0.99754). Neither individual run reaches the six-point length conventionally required by the Western Electric/Nelson rules to declare a formal trend signal [7], so no alarm would have been triggered under strict SPC criteria; nevertheless, the coincidence of two short downward runs within a five-voyage window is operationally noteworthy and illustrates the diagnostic value of visual

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control-chart inspection even below formal alarm thresholds, and is more consistent with two distinct assignable causes than with a single progressive drift mechanism such as continuous sediment accumulation.

4.4 Distribution of the Ship-Shore difference

Figure 2 shows the distribution of the percentage difference between ship and shore figures for all 23 voyages, together with a fitted normal density and the ±0.3% tolerance lines. The distribution is unimodal and reasonably symmetric around a small negative mean, with no observations approaching the ±0.3% boundary from either side; the three STS voyages excluded from the VEF calculation (hatched bars) are distributed similarly to the qualified population rather than forming a separate cluster, which supports treating their exclusion as a procedural rather than a statistical adjustment.

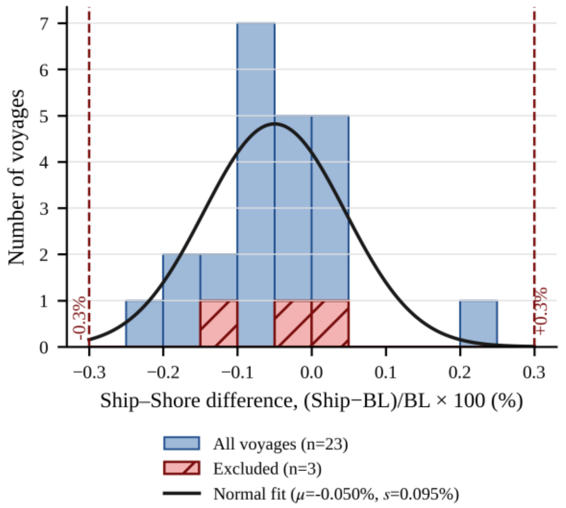

Figure 2 Distribution of the Ship-Shore percentage difference for 23 voyages, with a fitted normal density (μ = -0.050%, s = 0.095%) and the ±0.3% tolerance lines.

5. DISCUSSION

The case study demonstrates that a data set collected purely for commercial loss-control purposes can be read, without any additional instrumentation or data collection, as a small but genuine SPC data set. The clearest illustration of the added value of this reframing is the 241-246 window: none of the five voyages individually breached the ±0.3% tolerance, so a conventional per-voyage reconciliation check would have raised no flag at any point in the sequence, yet the control-chart view highlights two short, directionally consistent runs that would be worth a documented investigation - re-checking ullage readings, temperature stratification, density correlation and trim/list corrections - well before any single voyage approaches the tolerance limit.

Several limitations should be acknowledged. The analysis is based on a single vessel over a one-year operating window, so the results describe the measurement behaviour of that vessel rather than of the product-tanker fleet in general; extending the approach to a multi-vessel, pooled data set is a natural next step. The sample size (n = 20-23) is modest relative to the minimum of about 25 individual observations conventionally recommended for estimating stable Shewhart control limits [7], and consecutive voyages of the same vessel are unlikely to be fully independent, since they share instrumentation, calibration tables and often crew - a form of serial dependence that classical control-chart theory does not assume. The Shapiro-Wilk result and the run-length argument in Section 4.3 should therefore be read as indicative screening tools rather than as confirmatory hypothesis tests. It is also worth noting that all three STS voyages excluded under the API MPMS 17.9 eligibility rule in fact fell inside the ±0.3% band (Section 4.4); while the procedural exclusion of STS transfers from the baseline calculation remains prudent given the additional third-party measurement involved, this observation suggests that, for a modern tanker with redundant radar/UTI gauging, the exclusion may be conservative - an empirically testable question on a larger sample.

The proposed approach is complementary to, rather than competitive with, other strands of tanker-measurement research. Meškuotienė et al. [9] address the instrument-level metrological uncertainty of liquid-level gauging, and Senol [8] addresses the human and organisational contribution to cargo-shortage incidents through fault-tree analysis; the present study adds an intermediate, operational layer, using data that every tanker already generates, to monitor whether the ship/shore measurement process for a specific vessel remains statistically stable over time. In practice, the approach requires no more than plotting each new voyage's ratio against the standing VEF baseline and its ±0.3% band, and flagging any run of three or more consecutive voyages moving in the same direction - a check that can be implemented in a simple spreadsheet or in the cargo-calculation software already carried on board, since the underlying figures are already generated for the Letter-of-Protest and VEF-update process.

6. CONCLUSIONS

This study repurposed the Vessel Experience Factor, a long-established cargo-reconciliation and loss-

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control instrument, as a lightweight statistical process-control indicator for the ship/shore cargo-measurement process. Using 23 consecutive loading operations of an product/chemical tanker, the historical VEF (0.99947 over 20 qualified voyages) was shown to be fully compatible with the vessel's own ±0.3% commercial tolerance acting as Shewhart-type control limits, with all 23 voyages remaining inside the band and the sample distribution consistent with normality. The individuals control chart identified a genuine, if modest, five-voyage episode of directional drift that was not visible to a conventional single-voyage tolerance check, illustrating the practical value of the proposed reframing. Because the required data are already generated for commercial reconciliation purposes, routine control-chart monitoring of the Ship/Shore ratio can be adopted by ships' staff at essentially no additional cost. Future work should extend the analysis to a multi-vessel, fleet-level data set to test the generality of the observed behaviour, apply more sensitive charts such as EWMA or CUSUM to the small sustained drifts identified here, and explore integration of the proposed monitoring scheme into digital cargo-management and loss-control software.

7. CREDIT AUTHORS STATEMENT DATA

Conceptualization: N.A.; Methodology: A.P.; Software: V.A.M.; Validation: V.A.M.; Formal analysis: N.A.; Investigation: V.A.M.; Data curation: A.P.; Visualization: A.P.; Writing - original draft: V.A.M. and N.A; Writing - review and editing: A.P

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