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RISK-BASED MODEL FOR ASSESSING CARGO DISCREPANCIES IN TANKER OPERATIONS

Summary. *This article develops a risk-based model for assessing cargo quantity discrepancies during tanker loading and discharge operations. The model treats a final ship-shore difference as the possible result of several interacting groups of factors: measurement uncertainty, cargo-system condition, operational execution, documentation integrity, and ship-shore coordination. The research uses a conceptual and methodological design based on international risk-management principles, petroleum measurement standards, and tanker-terminal operating guidance. The proposed Risk-Based Cargo Discrepancy model (RBCD) assigns each identified factor scores for probability, impact, and difficulty of early detection. It then links the resulting priority score to an operational stage, control action, responsible person, and evidence record. An illustrative scenario shows how a moderate total operational index may coexist with one or more high-priority factors that require immediate verification. The scientific novelty lies in combining technical measurement causes and operational information weaknesses within one stage-based framework. The model is intended as a decision-support instrument and does not replace contractual measurement procedures, approved vessel or terminal instructions, or professional judgment.*

Key words: *tanker operations, cargo discrepancy, risk assessment, cargo reconciliation, petroleum measurement, ship-shore coordination, loss control.*

Introduction. Marine transfers of crude oil and petroleum products require the parties to compare quantities generated by different measurement systems and under different physical conditions. Vessel calculations depend on tank calibration tables, observed levels, trim and list corrections, temperature, density, free water, on-board quantities, and remaining-on-board material. Shore figures may be based on calibrated tanks or meters and may include line displacement and terminal-specific corrections. A numerical difference between vessel and shore results is therefore not self-explanatory. It may indicate a physical cargo gain or loss, a measurement effect, a system-boundary difference, or incomplete alignment of the underlying data [3-8].

Final reconciliation is necessary but reactive. By the time a discrepancy is visible, pipeline condition, valve positions, temporary records, and witness recollection may no longer be directly verifiable. A risk-based approach begins earlier by identifying conditions capable of producing or concealing a difference and defining the controls and records required before the operation is closed.

ISO 31000 defines risk management as a coordinated process of identification, analysis, evaluation, treatment, monitoring, communication, and recording [1]. IEC 31010 provides methods for selecting and applying risk-assessment techniques under uncertainty [2]. These general principles are compatible with tanker operations, but they do not provide a marine-cargo-specific model. The purpose of this study is therefore to develop a compact methodology that translates them into a practical cargo-discrepancy assessment framework.

Literature Review and Theoretical Framework. The API Manual of Petroleum Measurement Standards provides the principal technical basis for marine cargo accountability. API MPMS Chapter 17.1 addresses marine cargo inspection and the recording of essential data; Chapter 17.2 explains the complexity of measuring materials contained in vessel tanks, lines, slop tanks, and other spaces; Chapter 17.5 addresses voyage analysis and reconciliation; Chapter 17.6 focuses on pipeline fullness; and Chapter 17.9 governs the calculation and use of the vessel experience factor [3-7]. API MPMS Chapter 13.3 further emphasizes that reported measurement results must be interpreted together with their uncertainty [8].

Operational guidance reaches the same conclusion from a different direction. The International Safety Guide for Oil Tankers and Terminals requires continuous ship-shore communication, agreement on transfer conditions, and repeated verification of controls throughout the operation [9]. The OCIMF Marine Terminal Information Booklet guidance stresses the value of accurate and current berth, terminal, and port information for reducing operational risk [10]. Taken together, these sources show that cargo reconciliation is not a single calculation. It is a process connecting measurements, physical systems, operational events, communication, and documentary evidence.

The methodological gap lies in prioritization: existing guidance does not combine all discrepancy-producing factors into one operational risk register. The proposed model addresses this gap through common scoring and stage-based evidence.

Materials and Methods. The study has a conceptual-methodological design. It does not use a proprietary voyage database and does not propose a universal contractual tolerance. The model was developed through comparative analysis of risk-management standards, petroleum measurement publications, and tanker-terminal guidance. The unit of analysis is a discrepancy factor: a condition, event, or information weakness capable of changing a reported cargo quantity or reducing confidence in the reconciliation process.

The model covers five operational stages: pre-arrival preparation, initial gauging and system verification, active cargo transfer, final measurement, and post-transfer reconciliation. At each stage the assessor identifies relevant factors, records the available evidence, and assigns three scores from 1 to 5: probability (P), impact (I), and difficulty of early detection (D). The product of these values forms the individual risk-priority score. The scale is ordinal rather than probabilistic; its purpose is transparent prioritization, not calculation of a physical loss amount.

$$R\_i = P\_i \times I\_i \times D\_i \quad (1)$$

The maximum factor score is 125. Proposed bands are 1-20 low, 21-45 moderate, 46-75 high, and 76-125 critical. A normalized operation risk index (ORI) may also be calculated, but the highest individual score must be reviewed separately because an average can conceal a critical factor.

$$ORI = [\Sigma R\_i / (125 \times n)] \times 100\% \quad (2)$$

The scientific novelty of the RBCD model is the integration of technical and information-quality factors within one sequence. Each score must be linked to a control, owner, completion time, and evidence record, and may be reduced only after the control is verified.

Classification of Cargo Discrepancy Factors. The first step is to classify factors by the mechanism through which they may affect the final result. Five groups are proposed (table 1).

Table 1

Classification of Cargo Discrepancy Factors

Factor group	Representative examples	Possible effect	Primary evidence
Measurement	Gauging, temperature, density, calibration, trim/list correction	Changes calculated vessel or shore quantity	Raw readings, calibration data, calculation sheets
Cargo-system condition	Line fullness, valve leakage, OBQ/ROB, free water, slop transfer	Changes the system boundary or retained quantity	Line displacement record, tank inspection, valve status

Factor group	Representative examples	Possible effect	Primary evidence
Operational execution	Tank switching, interruption, stripping, rate change, internal transfer	Creates unrecorded movement or incomplete transfer	Event log, pump log, valve sequence, rate record
Information integrity	Different timestamps, units, reference temperatures, transcription errors	Makes figures non-comparable or incorrectly processed	Source files, timestamps, version history
Ship-shore coordination	Unreported changes, inconsistent instructions, delayed confirmation	Prevents timely verification and common understanding	Conference record, checklist, messages, joint statements

Source: developed by the author

The classification prevents the investigation from focusing only on arithmetic. A difference may be mathematically correct within each party's own calculation while remaining operationally inconsistent because the parties used different times, boundaries, or treatment of line contents. For this reason, the model includes a data-alignment gate. Before judging the discrepancy, the assessor confirms that ship and shore figures use the same unit, reference temperature, quantity basis, observation time, cargo boundary, and treatment of free water and residual material.

Architecture and Scoring of the RBCD Model. The RBCD workflow consists of six consecutive stages shown in figure 1. The sequence is cyclical because the final reconciliation should generate lessons for the next operation.

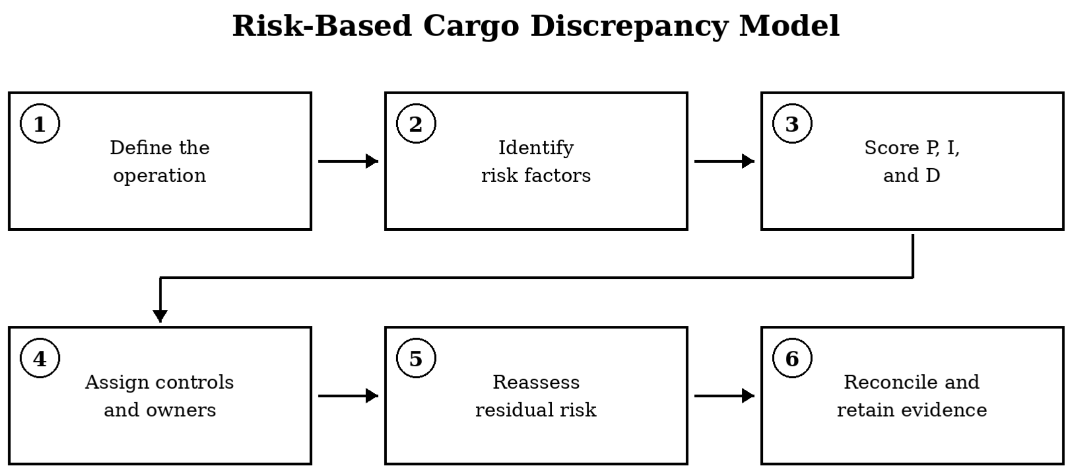

Fig. 1. Workflow of the Risk-Based Cargo Discrepancy Model

Source: developed by the author

Table 2

RBCD Scoring Criteria

Score	Probability (P)	Impact (I)	Detection difficulty (D)
1	Rare under current conditions	Negligible effect; routine correction	Immediately visible in normal records
2	Unlikely but credible	Minor operational or documentary effect	Usually detected by standard checks
3	Possible during the operation	Material review or additional verification required	May remain hidden until interim comparison
4	Likely without additional control	Significant commercial or operational consequence	Usually detected only after focused analysis
5	Expected or already indicated	Major consequence, dispute, or unreliable reconciliation	Difficult to detect before final reconciliation

Source: developed by the author

Scoring must be evidence-based. A high probability score may be supported by an observed abnormality, a first call at the terminal, a weak vessel or terminal history, or a complex transfer arrangement. Impact should consider not only the possible quantity effect but also the consequences for safety, delay, claims, and reliability of documents. Detection difficulty reflects the chance that the factor will remain unnoticed until the operation is complete. The model therefore gives additional weight to conditions that are both influential and hard to observe in real time.

Each factor is then assigned a control barrier. Examples include repeating a gauge, verifying instrument status, confirming line displacement, establishing a common event timeline, freezing the calculation version, checking tank distribution, or requiring joint review before final documents are signed. The control owner may be the vessel, terminal, inspector, cargo superintendent, or another authorized party. Responsibility must be explicit; otherwise a control can appear in the record without being completed.

Illustrative Application. To demonstrate the method, an illustrative discharge operation was evaluated using six representative factors. The figures are hypothetical and are included only to show the calculation logic; they do not represent a universal industry threshold or a real client operation (table 3).

Table 3

Illustrative Initial and Residual Risk Assessment

Factor	Initial P/I/D	Initial R	Control	Residual P/I/D	Residual R
Unconfirmed shore-line fullness	4/5/4	80	Joint line-displacement verification	2/4/2	16
Different final gauging times	4/3/3	36	Common measurement window and timestamps	1/3/1	3
Incomplete stripping record	3/4/4	48	Pump/event log and ROB confirmation	2/3/2	12
Manual transcription of density	3/4/3	36	Source-file import and independent check	1/3/1	3
Limited validated VEF history	3/3/4	36	Use VEF only with qualification statement	2/2/3	12
Unrecorded tank-switching time	3/3/4	36	Joint event timeline and rate review	1/2/2	4

Source: developed by the author

The initial maximum score is 80, which places unconfirmed line fullness in the critical category. The operation should not be interpreted as low-risk merely because several other factors are moderate. After the controls are completed and documented, the maximum residual score decreases to 16. This example demonstrates why the model uses both the normalized ORI and the maximum individual score. The normalized index describes the overall profile, while the maximum score prevents averaging from concealing a single dominant factor.

The example also shows the distinction between identifying a plausible cause and proving a physical loss. The model does not conclude that the line condition caused a particular quantity difference. It concludes that the condition has sufficient probability, impact, and detection difficulty to justify targeted verification and preservation of evidence. Causal attribution remains a separate reconciliation task governed by the quality of the available data.

Operational and Digital Implementation. The model may be implemented in a structured spreadsheet, database, or Power Apps-based workflow. The record should contain the operation, stage, factor, factual observation, source evidence, P/I/D scores, control, owner, due time, completion evidence, residual score, and final disposition. Alerts may identify high scores or overdue controls.

Digitalization does not improve reconciliation by itself. Its value depends on disciplined data entry, controlled calculation versions, preserved source records, and clear authority for changing scores. A system should retain the original assessment and every subsequent revision. This creates an audit trail showing what was known at each stage, what action was selected, and why the residual risk was accepted. The same data may later support trend analysis across vessels, terminals, cargoes, and recurring causes.

The model is particularly useful for first calls, complex tank distributions, nonstandard line displacement, unusual cargo characteristics, significant interruptions, unstable interim comparisons, limited VEF history, or incomplete event records. It should be integrated into existing pre-transfer conferences, loading or discharge plans, inspection records, and final reconciliation files rather than introduced as a disconnected administrative form.

Discussion. The proposed model changes the starting point of discrepancy management. A conventional approach begins with the final numerical difference and works backward. The RBCD model begins with the operational conditions capable of producing or obscuring the difference and follows them forward through controls and evidence. This improves traceability and permits corrective action while the operation is still observable.

The risk register also connects vessel, terminal, inspection, and commercial perspectives without assuming that one party's figure is automatically exact. This is consistent with measurement-uncertainty principles and API guidance requiring reconciliation of multiple data sources [3-8].

The scoring scale is ordinal and includes expert judgment. Different users may assign different scores without examples and calibration training. The model does not calculate physical loss, and its thresholds require validation against operational history. It should therefore be piloted, compared with reconciliation outcomes, and adjusted on the basis of recurring evidence.

Conclusions. Cargo discrepancies in tanker operations are multi-source outcomes. They may result from measurement uncertainty, cargo-system condition, execution of the transfer, information integrity, or ship-shore coordination. A final ship-shore difference cannot by itself identify the underlying mechanism.

The RBCD model provides a structured sequence for defining the operation, identifying factors, assigning P/I/D scores, selecting controls, documenting responsibility, reassessing residual risk, and retaining evidence for reconciliation. The data-alignment gate is essential: figures should not be treated as directly contradictory until their units, reference conditions, timestamps, system boundaries, and treatment of line contents and residual material are aligned.

The main practical advantage of the model is early prioritization. It directs attention to a small number of high-value factors before the final discrepancy becomes fixed and difficult to investigate. The model is conceptual and requires empirical validation. Future research should test inter-rater consistency, compare scores with actual reconciliation outcomes, and determine whether digital implementation reduces missing evidence, investigation time, and recurrence of unresolved causes.

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