Analysis of Ethylene Propene Cargo Loss During Discharge Using Root Cause Analysis

Zulfaidah Ariany[1*], Muhammad Alif Fadhil Rizqi[2], Halim Tri C[3], Arwen Surya A. A[4]

(Received: 10 March 2026 / Revised: 15 March 2026 / Accepted: 30 March 2026 / Available Online: 3 June 2026)

Abstract**—** The transfer of ethylene–propene cargo from LPG/C vessels to onshore storage tanks is a critical operation in maritime logistics, where measurement accuracy, temperature correction, and transfer system performance significantly affect cargo integrity and operational efficiency. This study aims to evaluate cargo loss during the discharge process and to identify the main contributing factors affecting the discrepancy between ship and shore measurements. The analysis was conducted using quantitative calculations based on tank sounding data and temperature correction using a shrinkage factor approach. In addition, Root Cause Analysis (RCA) was applied using fishbone diagrams and cause-and-effect matrix methods to systematically identify and prioritise the potential causes of cargo loss. The results show that the total cargo mass after correction reached 7,657.732 MT. A comparison between ship and shore tank measurements indicates a discrepancy of 78.482 MT (−2.294%), confirming the occurrence of cargo loss during transfer operations. The RCA results reveal that suboptimal vapour return system performance and temperature-induced density variations are the dominant causes, supported by measurement inconsistencies and operational factors.

*Keywords***—** Ethylene Propene, Cargo Loss, LPG Carrier, Root Cause Analysis, Temperature Correction.

[*]*Corresponding Author:zariany@live.undip.ac.id*

I. INTRODUCTION

In the world of shipping and logistics, the process of transferring goods from ships to terminals is a crucial stage that requires special attention. One of the challenges often faced is the loss of goods and excess or insufficient cargo [1], especially in the transport of chemicals such as Ethylene Propene. The XXX Leda ship operating at Terminal XXX is highly susceptible to both problems during the unloading process.

Ethylene Propylene Diene Monomer (EPDM) is a versatile synthetic rubber widely used in various industries due to its elasticity and resistance to heat, ozone, UV rays, and extreme weather conditions [2]. EPDM is often used to make seals, gaskets, hoses, cable insulation, and automotive components such as door seals, weather seals, and cooling systems [3]. In addition, this material is also used in construction as roofing membranes, pipe linings, and swimming pool linings due to its resistance to water and various mild chemicals [4][5][6]. With its excellent electrical insulation properties, EPDM is also widely used in cables and electrical equipment, making it an important material that provides protection, durability and flexibility in a wide range of technical applications [7]. The transportation of liquid goods is crucial to ensure that these goods can be delivered to areas that lack adequate infrastructure or favourable natural conditions. These areas may not have adequate rail or air transport access, or may not have suitable embankments along rivers, lakes or seas with adequate loading and unloading facilities [8].

Goods loss refers to the loss of goods that occurs during the transportation process. This phenomenon is a major concern in various sectors, including logistics, product distribution, and supply chains [9]. In the context of freight transport, loss of goods can cause significant financial losses and affect the operational efficiency of the company [10]. Data shows that many companies experience high levels of goods loss due to various factors, such as packaging defects, delivery errors, and theft [11].

Loss or damage to goods is a very common problem faced by almost all businesses that have supply chains, which can lead to serious issues such as loss of revenue and damage to reputation [12]. Several factors that cause cargo loss are unstable wave conditions at the dock, which make it difficult to read the depth of the ship [13]. In addition to errors in reading the depth of the ship, cargo losses can also occur due to spillage during unloading or loading activities from the dock to the ship or vice versa [14].

In addition, there is also overloading, which can be defined as excess cargo that exceeds the safe capacity limit for a ship [15]. Each vessel is designed with specific specifications, including limits on the weight and volume of cargo it can carry. Exceeding these capacities can compromise the stability and safety of the vessel and potentially cause accidents [16]. One factor that causes overloading is inaccuracy in calculating the weight or volume of goods, which can result in loads exceeding safe capacity limits [17]. Therefore, problems

Zulfaidah Ariany with Department of Engineering Technology, Universitas Diponegoro, Semarang, 50275, Indonesia. E-mail:zariany@live.undip.ac.id

Muhammad Alif Fadhil Rizqi with Department of Engineering Technology, Universitas Diponegoro, Semarang, 50275, Indonesia. E-mail:aliffaddhil766@gmail.com

Halim Tri Cahyono with Department of Engineering Technology, Universitas Diponegoro, Semarang, 50275, Indonesia. E-mail:halimtri@students.undip.ac.id

Arwen Surya Adi Anjalu with Department of Engineering Technology, Universitas Diponegoro, Semarang, 50275, Indonesia. E-mail:arwensurya220704@gmail.com

with cargo loss or excess cargo usually occur during the loading process because they are based on the concept of comparison set out in the Bill of Loading [18].

Preventing damage to goods should be a top priority in every shipping operation. This involves understanding the factors that cause damage to goods and implementing best practices in unloading procedures [19]. Ensuring that distribution activities run smoothly, safely, and efficiently is also important for maintaining the company's reputation and minimising the risk of greater economic losses in the future [20].

This study aims to identify problems related to the loss of Ethylene Propene cargo and propose solutions for a simple calculation programme that can be implemented. Minimising losses during the unloading of ethylene propene cargo at Terminal XXX. With all efforts made, it is hoped that the safety and efficiency of ship operations can be maintained properly.

II. Method

The analysis method was carried out using quantitative calculations in Microsoft Excel to determine load differences. Excel is equipped with Data Analysis Toolpak, an add-in that provides more in-depth data analysis capabilities, including descriptive statistics, correlation, and regression analysis. For more specific needs, Visual Basic for Applications (VBA) can be used to create custom tools in Excel, enhancing its functionality for specific tasks such as multiple comparisons and complex data manipulation [21].

RCA (Root Cause Analysis) through fishbone diagrams and cause-and-effect matrix methods, which visually illustrate the relationship between problems (effects) and their potential causes, which are attached to key areas such as personnel, methods, materials, and the environment. This tool assists in brainstorming and organising the potential causes of a problem in a structured manner [22][23]. Cause-and-effect matrices, on the other hand, are used to prioritise and analyse the relationships between various causes and their effects [24]. By assigning scores and rankings to causes based on their impact and frequency, this matrix provides a quantitative approach to RCA, complementing the qualitative insights from the fishbone Diagram [25].

The data in this study utilised the LPG/C XX vessel sailing between Yosu Port in South Korea and Merak Port in Indonesia as the main object of observation. The data used in this study was obtained from three main sources, namely the results of systematic measurements of the initial and final cargo volumes in the ship's tanks before and after the voyage, data received from measurements taken from land tanks at the receiving terminal, which was used to verify cargo transfer and detect potential volume losses, and various operational documents supporting the shipping process, including the Bill of Lading, Cargo Quality Analysis Certificates, and Inspection Certificates issued by independent supervisory agencies. These three data sources were consolidated and comprehensively analysed to evaluate the accuracy of cargo measurements, the reliability of transfer procedures, and factors contributing to volume deviations during maritime LPG transportation.

TABLE 1.
LPG/C SHIP SPECIFICATION

Dimension	Notation	Value (m)
Length Overall	L_{OA}	114,89
Length Between Perpendicular	L_{BP}	109,51
Breadth	B	16,80
Height	H	11,83
Depth	D	6,60

TABLE 2.
T-02 SAU SPECIFICATION

Dimension	Notation	Value
Measuring Hole Height	h_m	31,475 **(m)**
Tank Height	H	29,200 **(m)**
Maximum Net Volume	h_{max}	28,900 (mm)
Reference Height	h_o	10 (mm)
Bottom Height	h_β	0 (mm)
Temperature of Liquid Volume	T_v	-104℃
Temperature for Density Measurement	$T\rho$	-104℃ / 0,570 g/ml

III. Results and Discussion

The calculation results show a load difference of –2.294% between the ship and shore tank measurement data. This difference is calculated based on the volume and density corrected for load temperature.

The apparent volume of 13,465.454 KL, after correction with the shrinkage factor, resulted in

13,463.632 KL. With an average density of 561.1 kg/m³, the recorded liquid mass was 7,598.525 MT. In addition, the net vapour volume of 3,027.235 KL, after correction with the expansion factor, resulted in 3,026.339 KL, which is equivalent to 59.207 MT of gas mass. The total cargo (liquid + vapour) reached 7,657.732 MT. However, a comparison with the onshore tank data showed a deficit of 78.482 MT, indicating a loss of cargo during the transfer process.

This finding confirms that the phenomenon of cargolosses is not only influenced by the volatile nature of Ethylene Propene as a cryogenic cargo, but also by technical and operational factors. Inconsistent measurement instruments are a classic issue in the loading and unloading process, while suboptimal vapour recovery systems increase losses due to BOG. From an operational perspective, a combination of technical factors (measurement systems, pipes, and coolers) and human factors (surveyor accuracy and data recording) are the main causes of losses. Therefore,From an operational perspective, the combination of technical factors (measurement systems, pipes, and coolers) and human factors (surveyor accuracy and data recording) are the main causes of losses. Therefore, mitigation strategies need to focus on the integration of Automatic Measurement Gauge (ATG), optimisation of the vapour recovery system, and standardisation of procedures between ships and terminals.

A. Technical Compliance Analysis

Based on initial measurements on board the vessel and after comparing the total quantity based on initial measurements on board with the quantity discharged based on measurements from the shore tank, a loss of -2.294% was found in the ethylene propene cargo. This difference was calculated based on the volume and density adjusted for the loading temperature.

This measurement is carried out to determine the total volume of cargo received by the land terminal, which is then adjusted for temperature, density, and other volume factors such as VCF (Volume Correction Factor) to obtain the standard volume at the reference temperature [26].ly influenced by the volatile nature of Ethylene Propene as a cryogenic cargo, but also by technical and operational factors. Inconsistent measurement instruments are a classic issue in the loading and unloading process, while suboptimal vapour recovery systems increase losses due to BOG. From an operational perspective, a combination of technical factors (measurement systems, pipes, and coolers) and human factors (surveyor accuracy and data recording) are the main causes of losses. Therefore,From an operational perspective, the combination of technical factors (measurement systems, pipes, and coolers) and human factors (surveyor accuracy and data recording) are the main causes of losses. Therefore, mitigation strategies need to focus on the integration of Automatic Measurement Gauge (ATG), optimisation of the vapour recovery system, and standardisation of procedures between ships and terminals.

1. Calculating Apprance Volume Observe

   Level Liquid = 23,730 m
   Av = 23,730 m
   Av = 13.465,454+0
   Av = 13.465,454 KL

   Based on a liquid level of 23,730 m, the apparent volume (Av) obtained is 13,465.454 KL.

2. Calculating to find the value Shrinkage Factor Liquid (Expansion Factor)

   α = 0,0000348
   t.liquid = -100°C

   $$1+\alpha \times (t - T) \quad (1)$$
   = 1+ 0,0000348 × (-106°C - (-100°C))
   = 0,9997912

   With an expansion coefficient (α) of 0.0000348 and a temperature difference between -106°C and -100°C, The thermal correction factor obtained is 0.9997912.

3. Calculating to find the Observation Volume value Liquid

   $$\text{Corrected Volume} = \text{Apparent Volume} \times \text{Shrinkage Factor} \quad (2)$$
   = 13.465,454 × 0,9997912
   = 13.463,632 KL

4. Calculating to find the value of Mass Liquid

   $$\text{Mass} = m\omega \times \text{Corrected Volume} \quad (3)$$
   = 561,1 × 13.463,632
   = 7.598,525 MT

5. Calculating to find the value of Volume Vapor

   Net Volume = 16.493,695
   $$\text{Net Volume} = \text{Av Liquid} \quad (4)$$
   = 16.493,695 - 13.465,454
   = 3.027,235 KL

6. Calculating to find the Vapour Shrinkage Factor (Expansion Factor)

   α = 0,0000348
   t.vapor = -97,5°C

   $$1+\alpha \times (t - T) \quad (5)$$
   = 1+ 0,0000348 × (-106°C - (-97,5°C))
   = 0,9997042

7. Calculating to find the Observation Volume value Vapor

   $$\text{Volume Vapor} \times \text{Shrinkage Factor Vapor} \quad (6)$$
   = 3.027,235 × 0,9997042
   = 3.026,339 KL

8. Calculating to find the value of the Ethylene propene Gas Factor

   M = 28,054
   P = 0,033 Bar
   = 0,0200851 MT

   The reason for using metric tonnes is because this formula is specifically designed to directly calculate the density or mass per volume of the actual gas in metric tonnes, in accordance with the requirements for calculating delivery and transfer of ownership (not just moles or grams).

9. Calculating to find the value of Mass Vappor

Obs. Volume Vappor = 3.026,339KL
Gas Factor = 0,0200851
Obs. Volume Vappor = Gas Factor (7)
= 3.026,339 KL × 0,0200851
= 59,207 MT

10. Calculating to find the value of Massa Total

Massa Liquid = 7.598,525MT
Massa Vappor = 59,207 MT
Massa Liquid + Massa Vappor (8)
= 7.598,525 MT + 59,207 MT
= 7.657,732 MT

11. Final Discharge – Initial Discharge (9)

This value represents the total volume or mass of cargo actually moved during loading and unloading activities. The calculation is generally used to verify the accuracy of cargo transfer operations, monitor potential cargolosses, and ensure data consistency between the ship and the receiving terminal [27]. Therefore, to calculate the total discharge, namely:

Discharge Final - Discharge Initial
7.657,732 MT - 4.235,793 MT
3.421,939 MT ≈≈ 3.500.421
3.500.421 MT - 3.421,939 MT
= 78,482 MT
≈ - 2,294 %

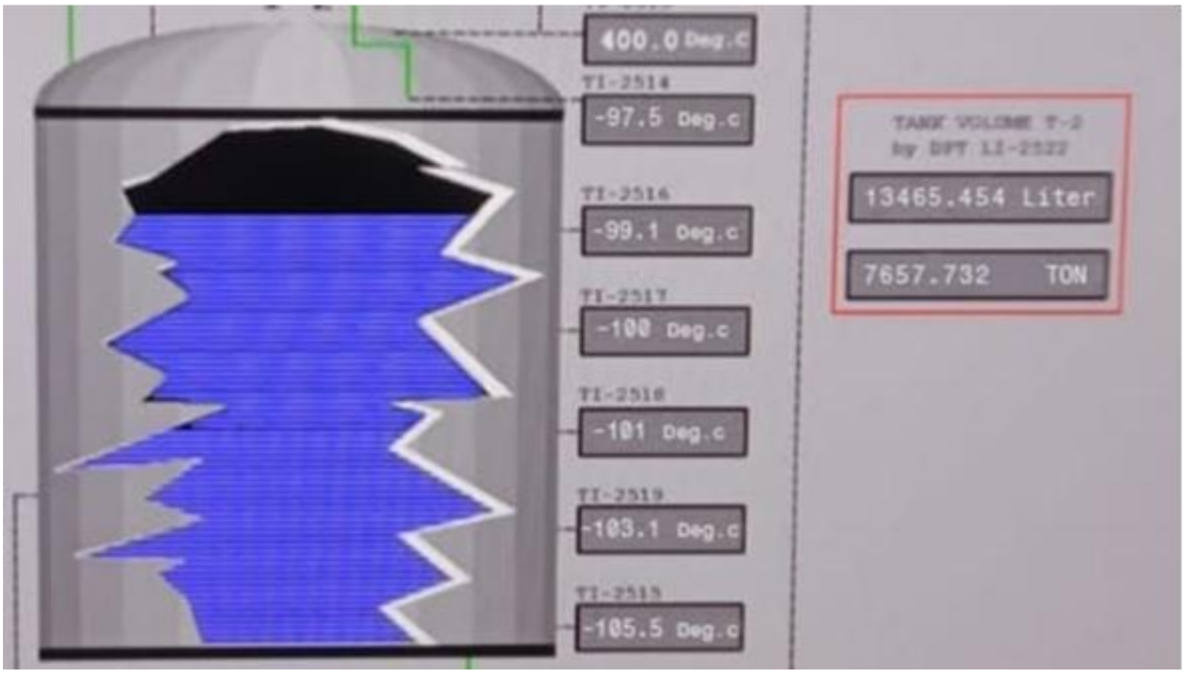

Figure. 1. Share Final Sounding Capacity

The total Discharge calculation shows that the difference between the final and initial measurements is 3,421.939 MT, while a comparison with the onshore tank data yields a figure of 3,500.421 MT, resulting in a difference of 78.482 MT or approximately -2.294%, indicating a loss of cargo during the transfer process.

B. Analysis Of Causal Factors

The Root Cause Analysis (RCA) results show that there are four main factors causing cargo loss in the ethylene propene unloading process. First, Boil-Off Gas (BOG), which is the evaporation of cargo that cannot be fully recaptured by the vapour recovery system, resulting in mass loss. Second, Pipeline Losses, which are cargo residues left in the piping system due to suboptimal vapour removal processes. Third, Measurement Discrepancies due to misalignment between ship and terminal measurement procedures, resulting in differences in cargo quantity data. Fourth, Temperature Correction Errors, namely discrepancies between actual cargo density and temperature correction values listed in reference tables, thereby affecting overall cargo volume and mass calculations.

C. Technical Compliance Analysis

The data was obtained from field investigations, investigation reports and interviews with the parties involved, where cargo losses during the unloading of ethylene propene were caused by a combination of interrelated technical and operational factors. The main causes included discrepancies between the measurements of the ship's tanks and the shore tanks, a suboptimal vapour recovery system that triggered vapour gas, and changes in cargo temperature and density that were not accurately corrected. In addition, cargo left in the pipes (pipe loss), mechanical leaks in hoses or valves, and human error in recording and data input also contributed to the difference in cargo quantities.

1. Differences in Measurement Methods and Tools (Measurement Inconsistency)
   - The ship uses an ullage Tamperature Indicator + Temperature Sensor and Calculates the volume based on the ship's tank calibration (tank table).
   - Shore tanks may use automatic level gauges or radar systems.
   - Differences in accuracy, instrument resolution, and calibration can cause differences in measured volumes.
2. Evaporasi (Boil-Off Gas Loss)
   - Ethylene is cryogenic and highly volatile.
   - During transfer, particularly when pressure or temperature changes occur, some ethylene may evaporate and enter the recovery or venting system.
   - If there is no vapour return line system or if the system is not functioning optimally, boil-off gas cannot be returned to the vessel.
3. Thermal Expansion and Density Changes
   - Temperature changes during discharge affect ethylene density.
   - If the temperature rises, the density decreases and the volume increases, but the mass remains the same, causing a discrepancy if the shore tank does not make temperature corrections.
4. Line Filling and Retention in Pipes (Pipeline Retention)
   - Significant amounts of ethylene can remain in transfer pipes, manifolds and loading arms, particularly in systems with long pipe runs.
   - If line blowing is not carried out or is not calculated accurately, the residue in the pipe is considered a loss.
5. Recondensation and Gas Venting
   - During transfer, some of the evaporated ethylene may be vented (to the atmosphere or to the flare system), especially when the shore tank pressure is too high.
   - Condensation delay may also occur, where ethylene gas has not yet had time to condense back into the shore tank.
6. Human Error
   - Sincorrect sounding reading, incorrect density data input, or neglecting temperature and pressure corrections.
   - The time recorded during the final sounding on the ship did not match the time recorded during the initial sounding on shore.
7. Mechanical Loss or Leakage
   - Potential for minor leaks in flanges, valves, or flexible hoses, although difficult to detect visually.
   - It can also occur in the vapour return line if it is not completely closed.

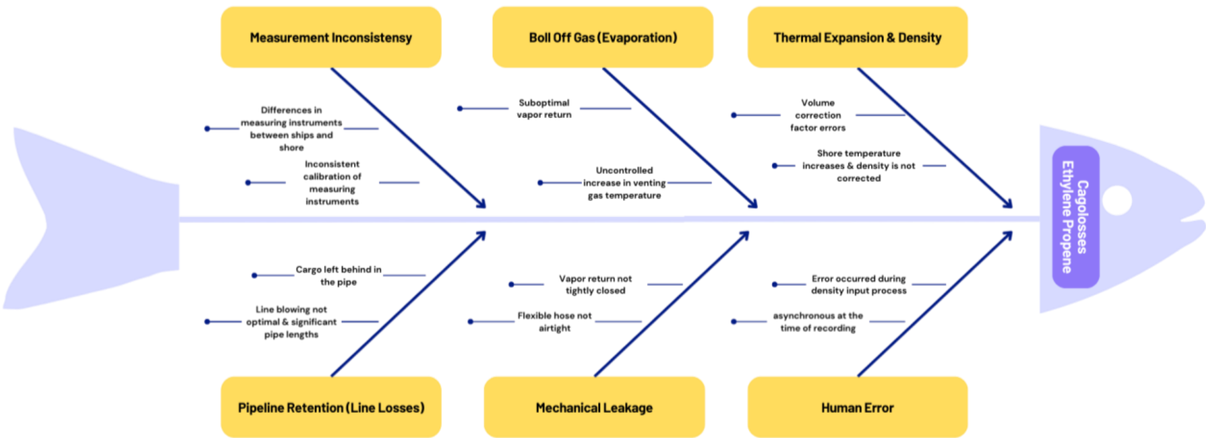

Figure.2. Fishbone Diagram

Visual analysis using fishbone diagrams shows that human factors (surveyor accuracy), measurement methods, equipment conditions, and cargo characteristics contribute to losses. These conditions emphasise that efforts to prevent cargo losses require a comprehensive approach through standardisation of measurement methods, optimisation of vapour recovery systems, mechanical maintenance, and improvement of surveyor accuracy.

D. *Creation of Caust Effect Matrix*

TABLE 3.
IDENTIFICATION OF CAUSAL FACTORS (PROCESS INPUT / X)

NO	Causal Factors (Input)
A	Differences in measurement methods between ships and shore
B	Suboptimal vapour return line
C	No line blowing of pipes after discharge
D	Changes in load temperature during transfer
E	Errors in sounding recording by operators
F	The condition of the valve and flange is not 100% airtight.

TABLE 4.
RELATIONSHIP ASSESSMENT (SCORE: 0 = NOTHING, 1 = LOW, 3 = CURRENTLY, 9 = STRONG)

Causative Factors (X)	Severity (S)	Occurrence (O)	Detection (D)	RPN (S×O×D)	Notes
Differences in measurement methods	5	4	4	80	Occurring due to differences in standards between ships and shore
Vapor return line suboptimal	9	8	6	432	Significant effect on pressure and evaporation, difficult to detect directly
No line blowing was performed	4	3	3	36	The impact is minor and relatively easy to anticipate with standard operating procedures.
Change in load temperature	9	7	5	315	Causing volume expansion and mass loss, a direct effect on losses
Sounding recording error	6	5	4	120	Human error, but it can be reduced with SOPs or digitization.
Valves and flanges are not airtight	7	6	5	210	Gas leaks can be significant, but they can still be detected by visual inspection.

TABLE 5.
PRIORITY ANALYSIS

Causative Factors (X)	Total Skor	Priority
Vapor return line is not optimal	432	Very High
Change in load temperature	315	Very High
Differences in measurement methods	80	Currently
Sounding recording error	120	Middle
Valves and flanges are not airtight	210	Middle
No line blowing was performed	36	Low

Conclusions from the C&E Matrix:

There are two factors that have the greatest impact on losses:

- Suboptimal vapour return lines, causing evaporated gas to escape into the atmosphere rather than returning to the tank.
- Changes in load temperature cause changes in ethylene density, which can lead to actual volume discrepancies if not corrected.

From these results, the two main causes (Suboptimal Steam Return Line and Load Temperature Change) should be the primary focus of the improvement strategy as they have the highest RPN values. These two factors can cause significant material losses if not controlled. Recommended immediate actions:

- Perform a thorough inspection of the vapour return system.
- Implementation of an automatic temperature monitoring system.
- Implement mitigation procedures to prevent losses during temperature changes (e.g., cooling control).

E. Creation of Caust Effect Matrix

Based on the results of research on cargo losses during the discharge of ethylene propene cargo, the main technical recommendations focus on improving measurement accuracy, optimising the vapour recovery system, and standardising operational procedures. This study recommends the following:

1. The implementation of Automatic Tank Gauges (ATG) for more precise measurement results.

The use of an Automatic Tank Gauge (ATG) that is capable of providing real-time and more accurate measurements of liquid levels and temperatures compared to manual methods. The use of ATG will also reduce the potential for human error during sounding and data recording. The integration of ATG with density-corrected calculation software is a strategic step to improve the reliability of cargo data.

2. Optimisation of the vapour recovery system to minimise boil-off gas.

The proven factor of Boil-Off Gas (BOG) contributing to cargo loss needs to be addressed through optimisation of the vapour recovery system. This device must be ensured to function efficiently to reduce unaccounted evaporation. In addition, the application of re-liquefaction and additional cooling procedures during transfer can be a solution to reduce the evaporation rate. Routine inspection and maintenance of the vapour recovery system must be carried out in accordance with ISGOTT and OCIMF standards to maintain technical functionality.

3. Standardisation of line stripping procedures in accordance with ISGOTT.

A standardised pipeline cleaning method should be implemented to minimise residual cargo trapped within the piping system. Line blowing or displacement procedures using inert gas should be part of discharge operations to ensure there is no significant cargo retention. These measures not only reduce cargo losses but also improve cargo transfer efficiency.

4. Factor difference in measurement methods between ships and shore tanks.

The procedures for recording sounding, density, and temperature need to be aligned with the use use of the same thermal correction tables so that the calculation results do not cause discrepancies. In addition, calibration of measuring instruments both on board and at the terminal needs to be carried out regularly to ensure accuracy and consistency.

5. Human Error.

Special training for surveyors, ship operators, and terminal officers in measuring and recording cargo data must be carried out in a structured manner. The implementation of a digitization system for operational documents is also recommended to minimize manual input errors.

With comprehensive implementation of these technical recommendations, it is hoped that the risk of cargo loss on Ethylene Propene can be significantly reduced, so that unloading can be carried out more safely, efficiently, and in accordance with international standards.

IV. CONCLUSION

Based on an analysis of the loss process in the cargo of Ethylene and propene using the Root Cause Analysis method, it can be concluded that cargo loss is mainly caused by evaporation or evaporated gas. Losses also result from cargo accumulation in transfer pipes (pipe losses), differences in measurement methods between ships and terminals, and temperature and pressure fluctuations during cargo transfer. Calculations show a difference of -2.294% of the total cargo, which stems from differences between ship measurement data and onshore tank measurements. Through the application of a fishbone diagram and cause and effect matrix, it was identified that the two main causes of cargo loss were the suboptimal performance of the vapour return pipe system and temperature fluctuations affecting cargo density. Although field investigations confirmed that all operational procedures were carried out according to standards, the characteristics of ethylene as a highly volatile cryogenic cargo remained a major challenge in maintaining cargo integrity. Therefore, the recommended solutions include optimising the vapour return system, implementing an automatic temperature monitoring system, using cargo calculation software, and standardising measuring instruments and measurement procedures on ships and at terminals.

ACKNOWLEDGEMENTS

The author would like to express his deepest gratitude to all parties who have supported all of this research activities. The author would also like to express his deepest gratitude to the Risk Assessment Laboratory Design Department of Industrial Technology, Vocational College, Universitas Diponegoro.

REFERENCES

[1] [1] K. A. Adeleke and A. A. Adepoju2, "C A Publication of (lie Schnnl of Scicnccs. Kcdcrnl ln i'trs ilv of Trchnotng)," Akur NiRcrin. *Journal o f Research in Science and Management.,* vol. 6, 2009.

[2] H. Dikland and M. van Duin, "A chemical modification approach for improving the oil resistance of ethylene-propylene copolymers," in Current Topics in Elastomers Research, 2008, pp. 395–412. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84939846858&partnerID=40&md5=24c0d8c020c0400ceb13101900670ae4

[3] N. L. Costa et al., "A Review of EPDM (Ethylene Propylene Diene Monomer) Rubber-Based Nanocomposites: Properties and Progress," Polymers (Basel)., vol. 16, no. 12, 2024, doi: 10.3390/polym16121720.

[4] S. Wu, T. Han, V. Thakur, R. Weeks, C. Li Pi Shan, and J. Tuberquia, "Ultra High Molecular Weight NORDELTM EPDM for TPV and Low Hardness Molded Goods Enabled by Advanced Molecular Catalyst," in IOP Conference Series: Materials Science and Engineering, 2019. doi: 10.1088/1757-899X/548/1/012013.

[5] A. Mukhopadhyay, "SEM study of worn surface morphology of an indigenous 'EPDM' rubber," Polym. Test., vol. 52, pp. 167–173, 2016, DOI : 10.1016/j.polymertesting.2016.04.013.

[6] J. E. Vostovich and B. J. Mulvey, "Ethylene-propylene elastomers for wire and cable applications," in 5th EI Electrical Insulation Conference Materials and Application, EIC 1963, 2016, pp. 122–125. DOI : 10.1109/EIC.1963.7461761.

[7] J.-P. Barozier and A. Nicco, "Reaction of maleic Ethylene/malaeic anhydride statistical copolymers with polymines," 1970.

[8] K. Čižiūnienė, J. Matijošius, J. Liebuvienė, and E. Sokolovskij, "Comparison of the Relative Importance of Factors Affecting the Conveyance of Bulk and Liquid Cargo," Appl. Sci., vol. 14, no. 3, Feb. 2024, doi: 10.3390/app14031151.

[9] K. V Queiroz and J. M. Abe, "Logistical Challenges in Last-Mile Deliveries in the Outskirts of the City of São Paulo. An Analysis of the Cargo Theft and Robbery Rates of an E-commerce Company," in Smart Innovation, Systems and Technologies, 2025, pp. 261–270. doi: 10.1007/978-981-97-7419-7_23.

[10] S. A. Alsobhi, K. K. Krishnan, D. Gupta, and A. T. Almaktoom, "Analysis of damage costs in supply chain systems," Int. J. Ind. Syst. Eng., vol. 28, no. 1, pp. 70–98, 2018, doi: 10.1504/IJISE.2018.088565.

[11] O. V. Tarovik, A. S. Reutsky, and A. G. Topazh, "Estimation of Evaporation Losses of Bunker LNG," World Transp. Transp., vol. 18, no. 3, pp. 84–106, Dec. 2020, doi: 10.30932/1992-3252-2020-18-84-106.

[12] P. Gupta, A. Young, and A. Rao, "Investigating Cargo Loss in Logistics Systems using Low-Cost Impact Sensors," Academy and Industry Research Collaboration Center (AIRCC), Mar. 2022, pp. 197–206. doi: 10.5121/csit.2022.120618.

[13] M. T. Ruiz, J. Villagomez, G. Delefortrie, E. Lataire, and M. Vantorre, "Parametric rolling in regular head waves of the Kriso container ship: Numerical and experimental investigation in shallow water," in Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE, 2019. doi: 10.1115/OMAE2019-96341.

[14] Y. Susanto, "Analisis Penyebab Terjadinya Shortage Cargo Pada Kegiatan Transshipment Batu Bara Di Vessel Pada Pt.Sedayu Makmur Abadi," vol. 2, no. 1, 2023.

[15] S. Onyshchenko, O. Shibaev, and O. Melnyk, "Assessment of potential negative impact of the system of factors on the ship's operational condition during transportation of oversized and heavy cargoes," Trans. Marit. Sci., vol. 10, no. 1, pp. 126–134, 2021, doi: 10.7225/toms.v10.n01.009.

[16] W. Zhang, J. Cui, and D. Wang, "A Two-Step Approach for Evaluating the Dynamic Ultimate Load Capacity of Ship Structures," J. Mar. Sci. Eng., vol. 12, no. 2, 2024, doi: 10.3390/jmse12020219.

[17] M. Kaup, D. Łozowicka, K. Baszak, and W. Ślączka, "An Assessment of Stability and Strength of a Container Ship for Safety Compliance in Cargo Loading Plans," Appl. Sci., vol. 14, no. 1, 2024, doi: 10.3390/app14010345.

[18] J. E. Piercy, "Lost, Damaged and Astray Freight Shipments: Some Explanatory Factors," 1980. [Online]. Available: https://www.jstor.org/stable/20712585

[19] E. Akyuz and M. Celik, "Application of CREAM human reliability model to cargo loading process of LPG tankers," J. Loss Prev. Process Ind., vol. 34, pp. 39–48, 2015, doi: 10.1016/j.jlp.2015.01.019.

[20] A. Srikanth, S. Narasimhan, and S. Narasimhan, "Optimization of unloading operations in petroleum product storage terminals," Ind. Eng. Chem. Res., vol. 53, no. 35, pp. 13728–13735, 2014, doi: 10.1021/ie400389x.

[21] T. O. A. Lehtinen, M. V Mäntylä, J. Itkonen, and J. Vanhanen, "Diagrams or structural lists in software project retrospectives - An experimental comparison," in Journal of Systems and Software, 2015, pp. 17–35. doi: 10.1016/j.jss.2015.01.020.

[22] D. D. Shinde, S. Ahirrao, and R. Prasad, "Fishbone Diagram: Application to Identify the Root Causes of Student–Staff Problems in Technical Education," Wirel. Pers. Commun., vol. 100, no. 2, pp. 653–664, 2018, doi: 10.1007/s11277-018-5344-y.

[23] N. Rashwan, "Using cause & effect diagrams to rectify high vibration problems (Case study)," in Vibration Institute Annual Training Conference 2012, 2012, pp. 77–86. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84961894520&partnerID=40&md5=bde5dbb71f0a1d4eb2aa2b50b7c42e8c

[24] K. A. Amminudin, T. S. Enezi, M. A. Jubran, A. T. Hajji, A. S. Enizi, and Z. F. Bedoukhi, "Gas plant improves C3 recovery with Lean Six Sigma approach," Oil Gas J., vol. 109, no. 19, pp. 102–109, 2011, [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-

82755177515&partnerID=40&md5=1f6bb7c6a8512b05b57adc424cb35703

[25] D. P. Abellana, "A proposed hybrid root cause analysis technique for quality management," Int. J. Qual. Reliab. Manag., vol. 38, no. 3, pp. 704–721, 2021, doi: 10.1108/IJQRM-11-2019-0356.

[26] PT Sulfindo Adiusaha, T-02 Ethylene SAU. 2022.

[27] E. M. Evleth et al., "Calculation of the Reaction of Ethylene, Propene, and Acetylene on Zeolite Models," J. Univ. Pierre Marie Curie, vol. 1, no. 1, pp. 1–7, 1996.