OPTIMIZING OIL VESSEL TERMINAL LAYOUT: A COMPREHENSIVE LITERATURE REVIEW

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ABSTRACT

This research paper systematically explores oil vessel terminal layout optimization, emphasizing safety considerations, environmental impact assessment, and efficient infrastructure design. The study employs a comprehensive methodology involving literature review and data synthesis, delving into technical and organizational safety aspects, safety exclusion zones, and the key components comprising an oil vessel terminal layout. By providing a holistic overview and a visual representation of terminal infrastructure, this research contributes to a deeper understanding of the complexities involved, offering valuable insights for industry practitioners and future research endeavours in this domain.

Keyword: Oil Vessel Terminal, Layout optimization, Safety Considerations, Environmental impact assessment

Introduction

The global oil industry, with its intricate logistics and vast infrastructure, is the backbone of numerous economies and modern societies [1]. This intricate network includes oil vessel terminals and strategic points where oil is transferred, stored, and dispatched to meet international demands [2]. These terminals, often characterized by their complex layouts, must facilitate the efficient movement and storage of oil, ensuring minimal delays and maximizing throughput [1]. Over the years, various strategies, technologies, and designs have emerged to optimize the layout of these terminals, seeking to enhance their operational efficiency and reduce costs [3]. However, as the industry continues to evolve in the face of technological advancements, environmental concerns, and changing market dynamics, so does the need to understand and refine these layout strategies [4]. This research delves into the existing literature on optimizing oil vessel terminal layouts, offering a comprehensive review of historical perspectives, current best practices, and potential future directions in layout optimization [5]. By synthesizing these insights, this study aims to provide a cohesive understanding of the current state of knowledge in this domain and to identify gaps and opportunities for further research and application [6].

Methodology

This study adopted a systematic literature review methodology tailored to the oil vessel terminal layout optimization domain to ensure a rigorous and comprehensive topic exploration [7]. This approach began with identifying relevant databases and repositories where key sources of information might be housed [8]. Peer-reviewed articles, conference proceedings, industry reports, and academic publications were meticulously searched using predefined criteria and keywords to capture a wide spectrum of insights related to terminal layout optimization [9]. Once sources were identified, a multi-stage assessment process was used. This study involved an initial screening based on titles and abstracts and a more in-depth review of the complete texts to ensure relevance and quality [10]. Each selected publication was then critically analyzed to extract pertinent data, methodologies employed, findings, and implications [11]. The information was subsequently synthesized, allowing for patterns, gaps, and emergent trends in the literature to be highlighted [12]. This structured approach ensured that the review was exhaustive and representative of the current state of knowledge and set the foundation for drawing meaningful conclusions and identifying potential avenues for future research [13].

Result and Discussion

Technical and Organizational Safety Aspect

Industrial facilities safety fundamentals and best operational practices are established during the design and planning stage. For facilities manufacturing, storing, or transporting hazardous substances, the whole scope of safety issues is the most important consideration. In most cases, oil terminals are classified as such facilities. During the design and planning stage, there is an opportunity to foresee the location of all site components and, taking into account essential safety regulations and the operational experience (positive and negative) of similar facilities, to propose the best and the most secure technologies and equipment [14].

Environmental Baseline and Impact Assessment

For new oil terminals, an environmental baseline condition should be established by the oil terminal operator and submitted to the competent authority as part of the operating permit application. The baseline report should contain the information necessary to determine the state of soil and groundwater contamination to make a quantified comparison with the expected state upon definitive cessation of activities (decommissioning) [14].

Facility Siting, Layout and Land-Use Planning

Facility siting, layout, and land-use planning can significantly affect the hazards of the oil terminals. A thorough understanding of an oil terminal's risks will minimize these without adversely affecting commercial viability. New facilities offer an opportunity for the adoption of appropriate safety distances (regarding vulnerable areas and the community), new technology, inherently safer designs, and Good Industry Practices [14].

Safe Design

Where national equipment design and operation standards exist, the oil terminal operator and the competent authority should implement and inspect them. Equipment design within an oil terminal should, whenever possible, incorporate lessons learned from relevant incidents. The design of control rooms, ergonomics, and effective alarm systems are crucial, enabling front-line staff, especially control room operators, to accurately detect, diagnose, and address potential incidents [14].

Hazard Management

It refers to hazard identification and risk assessment, risk ranking, and further controlling or reducing risks to acceptable or tolerable levels. Hazard management should be considered in the design and planning stage and all other life cycle stages of the oil terminal by the investor, operator, and all other key stakeholders, as appropriate [14].

Emergency Planning

Potential emergencies, including accidents with large-scale impact, exist during all life-cycle stages of a complex industrial facility. The best and the most non-hazardous technologies and equipment selection during the design and planning stage, a sound safety culture, and a systems approach to process safety management reduce the potential for a significant accident but do not exclude it completely. Therefore, it is necessary to be prepared for the maximum credible worst-case scenario [14].

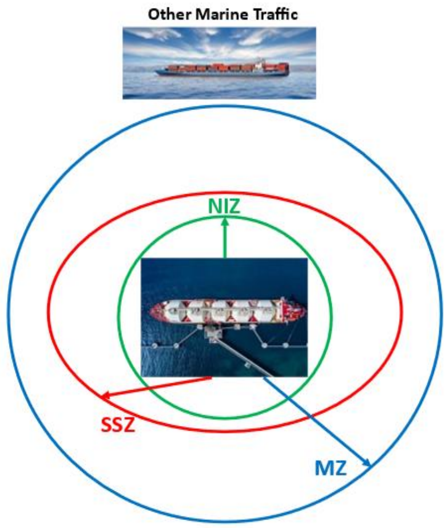

Figure. 1 Safety Exclusion Zone

Safety Exclusion Zone Around Oil Terminal

A safety Exclusion Zone is a delineated area or perimeter established around an oil terminal, where unauthorized access and activities are strictly prohibited to mitigate potential risks and ensure the safety of the infrastructure and the surrounding environment. This zone is instituted based on a comprehensive assessment of the possible hazards associated with the handling, storing, and transferring of hydrocarbons. Measures within the zone may encompass operational protocols, security procedures, and emergency response mechanisms to safeguard against any contingencies or threats, including spills, fires, or acts of sabotage. The boundary and enforcement of this zone underscore the imperative of proactive risk management in the oil and gas sector. As it is shown in Figure 1, This zone is divided into three parts [15]:

- Non-Ignition Zone (NIZ) – an area where non-essential people and vessel movements are not allowed, use of Personal Protective Equipment (PPE) is obligatory, and ignition sources must be avoided or strictly controlled. The NIZ may be determined by national regulations and as part of a Quantitative Risk Assessment (QRA).
- Safety and Security Zone (SSZ) – an area where only authorized vessels are allowed, specifically on business associated with the terminal, to avoid unnecessary risk in case of incidents at the terminal. The final SSZ size shall be determined with Hazard and Operability (HAZOP) and QRA during further terminal development.
- Marine Zone (MZ) – this is the exclusion zone around the terminal where, in principle, no other ships should sail except for vessels serving the terminal. If this is not possible due to site limitations, this is the area where all passing vessels need to be closely monitored. The marine (exclusion) zone is established to minimize collision risks from sailing ships that must pass the terminal. The final radius of the MZ will be determined by local Maritime Authorities, depending on the size of the vessels transiting and the speed allowed at the limit of the MZ.

Oil Vessel Terminal Layout

An oil terminal layout represents the systematic spatial arrangement of facilities and infrastructure designed to facilitate the efficient handling, storage, and transfer of hydrocarbons at a maritime interface. This layout encompasses several critical components:

- Breakwater

  A breakwater is a barrier constructed off the coastline to protect against swells, storms, currents, and tides. These structures are primarily made of stone and rocks, though wood has been utilized in some instances. Typically positioned in shallow waters to simplify construction, breakwaters can either be detached from the shore or connected to it. [16].

- Navigation channel

  The navigation channel is one of the main components of any harbour, facilitating ships' access to the harbour [17].

- Turning Basin

  A turning basin is a broader body of water, either located at the end of a ship canal or in a port, to allow cargo ships to turn and reverse their direction of travel or to enable long, narrow barges in a canal to turn a sharp corner [18].

- Berth/ Quay

  A berth is where the cargo is loaded or discharged on and off the ships. Each port or terminal will, in turn, have several berths/quays, which usually have shore equipment for handling cargo, covered sheds, open cargo storage areas, etc., where the cargo is discharged, loaded and may be stored. One container terminal can have several berths/quays where several ships can be handled simultaneously [19].

- Mooring Equipment

  A ship's mooring equipment includes tools and devices to secure the vessel to a berth. It includes winches and capstans for adjusting mooring lines, which can be ropes or steel cables. Fittings such as bitts and cleats secure these lines, while stoppers temporarily hold them. Other components like mooring chocks, rollers, pipes, and reels help manage and store the lines. Modern warping winches, which maintain line tautness and offer remote control, adapt to a ship's position changes due to cargo handling, tides, or waves. Classification societies regulate the size and specifications of mooring equipment and depend on various factors, including the ship's size and deck structures. [20].

- Storage Tank

  Tanks for storage are constructed from various materials, including steel, concrete paired with plastic, fiberglass-reinforced plastic, nylon, and polyethylene. Oil is predominantly stored in vertical steel cylindrical tanks. Specific regulations outline construction and material standards, and adhering to federal and state building and fire protection rules is essential when establishing a tank terminal. Tanks differ in design and equipment, with common types being fixed-roof (with or without an internal floating roof), external floating-roof tanks, cup tanks, and cryogenic tanks, which are substances that must be stored in liquefied form at extremely low temperatures. The paint on a tank can influence emission levels, with an aim in storage to minimize emissions. Crude oil tanks may also have stirrers or heaters to maintain consistency and viscosity. [21].

- Cargo oil Pump & Heater

  Liquid bulk cargoes are typically discharged from the vessel and loaded at the terminal using the vessel's pumps. When there is a significant distance between the terminal and the jetty, booster pumps may be used for discharging and loading operations. The heater is usually installed in the ship's Cargo tank to maintain the oil's viscosity [22].

- Marine loading arms

  A Marine Loading Arm loads or discharges the ship or vessel carrying oil. Marine loading arms comprise several sections of pipe (quick-connect fittings) connected by swivel joints. The section on the shore side of the 'apex' of the loading arm is known as the inboard arm, and the section on the tanker side of the 'apex' is known as the outboard section. Marine loading arms are flexible enough to accommodate vessel movement during loading/discharging. These hydraulically operated marine loading arms are fitted with emergency release couplings and emergency release systems and support faster and safer loading/unloading requirements [23].

- Pilotage and tugboat

  Around the world, many maritime countries use specialized marine pilots to navigate ships through domestic waterways. Pilots are professionally licensed mariners whose role is to board and assume the conduct of a vessel and guide it along the safest route to its port of call. A pilot's role is equally important as that of a captain. Although captains are experts at navigating their vessels, they are not experts on the regulations and specific environments of each port their vessels call. Therefore, captains require the local expertise of a marine pilot to ensure that their vessel and its crew, passengers, and cargo arrive at their next port of call safely and efficiently. Usually, tugboats assist in pushing or towing vessels during maneuvers [24].

- Loading Station

  Loading stations for trains and trucks may be present to connect the terminal to the hinterland. These loading stations are outfitted with specialized equipment for loading or discharging to a truck or train. The oil terminal is equipped with specialized installations for loading and unloading, having access to the pipeline network. It is a specialized terminal that can be used for the import of crude oil and gasoline, as well as for the export of refined petroleum products and petroleum products. Liquid bulk goods may also be transported through pipelines in the hinterland. The national pipeline network connects the port with the main refineries in the country, ensuring fast and safe transport. The terminal has the most modern and efficient anti-pollution and firefighting facilities [25].

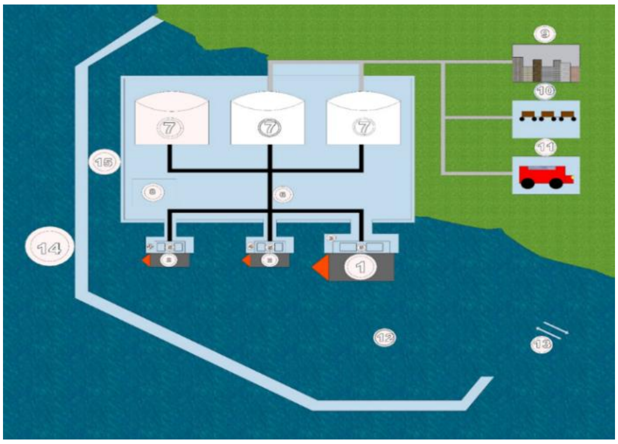

Figure 2. Oil Vessel Terminal Layout

Layout Description:

1. VLCC Vessel (160.000 – 320.000 DWT)
2. AFRAMAX Vessel and below (120.000 DWT and below)
3. Berth/ Quay for VLCC Vessel
4. Berth/ Quay for AFRAMAX Vessel and below
5. Loading Arm
6. Pipeline System from Oil Vessel to Oil Tank
7. Oil Tank
8. Security/ Cargo Monitoring Room
9. Pipeline to The Hinterland
10. Pipeline to Railway Filling Station
11. Pipeline to Oil Truck Filling Station
12. Turning Basin
13. Navigation Channel
14. Breakwater
15. Double Fences

Concerning the comprehensive data amassed on the constituent elements of an oil terminal, the researcher has endeavoured to conceptualize and represent an exemplary configuration of an oil vessel terminal layout. This illustrative model is systematically delineated in Figure 2. The figure serves as a visual encapsulation, integrating all components above, from breakwaters to loading stations, in a cohesive layout synthesized based on empirical observations and best practices within the domain. It aims to provide stakeholders with a spatial understanding of the potential interplay and adjacency of the terminal's critical infrastructure.

Conclusion

In conclusion, this research provides a comprehensive exploration of oil vessel terminal layout optimization, underscoring its significance in the global oil industry's operational efficiency and safety. Employing a systematic literature review approach, the study unveils pivotal elements such as technical and organizational safety measures, environmental impact evaluations, safety exclusion zones, and the detailed components of terminal layouts. These findings emphasize the paramount importance of incorporating safety and environmental considerations during the planning and design stages of oil terminals, with a consistent focus on meeting industry standards and regulations.

Moreover, the clear definition of safety exclusion zones and the detailed breakdown of components within an oil terminal layout present a thorough view of the complex nature of terminal infrastructure. The seamless integration of these elements, illustrated in the visual layout model, stands as a pivotal guide for stakeholders in terminal planning and management. This study not only deepens the understanding of challenges and prospects in streamlining oil vessel terminal layouts but also accentuates the ongoing shifts in the industry due to technological progress, environmental considerations, and market transitions.

Drawing from these insights, there is a highlighted need for continued research and innovation to bolster safety, operational efficiency, and ecological sustainability in the oil sector. The knowledge gained sets a robust foundation for future research and practical implementations in optimizing oil vessel terminal layouts, reinforcing the industry's dedication to secure, proficient, and sustainable oil transportation.

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