CHEMICAL ENGINEERING TRANSACTIONS
VOL. 77, 2019

A publication of
AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Genserik Reniers, Bruno Fabiano

ISBN 978-88-95608-74-7; **ISSN** 2283-9216

DOI: 10.3303/CET1977003

Layout - A Cost Effective and Powerful Design Step in Risk Management

SreeRaj R Nair[a,*], Jim Salter[b],

[a]GOM BU, Chevron USA Inc, Houston, USA
[b]ETC, Chevron, San Ramon, USA
snair@chevron.com

Management of risk to personnel and the environment in a major accident hazard (MAH) facility like offshore oil and gas production is a well acknowledged priority. Identification of the hazards, evaluating the potential for harm, analysis and implementation of the risk mitigation measures aCand safeguard stewardship are key for effective risk management.
Facility siting and layout is arguably the most influential design feature, but it can be problematic to get due regard in risk management during later design phases. Decisions on facility siting and layout are made during early design engineering phases and such decisions have the highest impact on the inherent risk profile of a MAH facility. This paper talks through a systematic approach for effectively utilizing layout in managing risk through establishing a layout philosophy, layout reviews.
This paper shares experience in utilizing technology (including enhanced QRA and 3D models) to determine engineered solutions for managing risk and risk-based decision making. It includes examples from recent oil and gas projects where concept selection and initial stages of engineering have considered risk-based approach for location selection, equipment selection, orientation and segregation, building siting and other options. The paper will demonstrate how a risk-based approach to facility siting provides an inherently safer design to minimize the reliance on add-on safety barriers.

Key words: facility siting and layout, quantitative risk assessment, risk management, safeguard stewardship, inherently safer design

1. Introduction

Managing Major Accident Hazards (MAHs) is fundamental to safe operations. Decision makers, leaders, design engineers involved in the engineering / project development of a MAH facility like oil and gas industry, onshore and offshore, has a part to play in managing these hazards. It is key to understand what a MAH is, how they are identified, and how they are mitigated. Successful MAH management establishes safeguards through systematic risk assessments (as a part of design process) and sustained safeguards (through inspection, testing, maintenance and appropriate management of changes).
In spite of the improvements made by the high hazard industries over the past decades, many major accidents resulting in multiple fatalities and significant environmental damage have happened. Lessons learned from some of the major accidents (Table 1) highlight the significance of site selection and layout as a safeguard in preventing or mitigating the consequences of incidents.
This paper shares experience in establishing siting and layout as a safeguard category and how it can be applied in major capital projects for MAH facilities. The concept and application techniques are explained with examples from recent oil and gas projects.

Paper Received: 4 October 2018; Revised: 18 May 2019; Accepted: 10 July 2019

Please cite this article as: Nair S., Salter J., 2019, Layout - A Cost Effective and Powerful Design Step in Risk Management, Chemical Engineering Transactions, 77, 13-18 DOI:10.3303/CET1977003

Table 1: Major accident highlighting the relevance of siting and layout as a safeguard

Incident	Year	Relevance to siting and layout
Flixborough; chemical plant explosion, onshore	1974	Onsite fatalities could have been prevented by appropriate Building siting – segregate the occupied building away from process area / process hazards
Bhopal; chemical industry release and toxic exposure (methyl iso-cyanide)	1984	Offsite fatalities could have been prevented with a secured buffer zone restricting development of non-industrial population; (lack of maintaining siting as a safeguard lead to rapid increase in density of population surrounding the area due to industrialization.
Mexico City; LPG explosion, onshore	1984	Offsite fatalities could have minimized with the storage tank design and orientation (storage under temperature or spherical shaped tank instead of bullet shaped metal tanks that resulted in projectiles)
Quebec (Lac-Mégantic); non-passenger rail incident	2013	Fatalities in the town could have been prevented if appropriate site (flat or low terrain to avoid reliance on brakes) was selected for rail car parking; (relying on engineered safeguard rather than appropriate site selection.
Mumbai High; fire at offshore oil & gas incident	2013	The incident and fatalities could have been prevented by locating the riser within the jacket (offshore platform structure restricting the impact from supply boat)

2. Systematic application in a Major Capital Project

To effectively utilize siting and layout as a safeguard in managing MAH, a systematic application with objectives and periodic reviews is required during early phases of Major Capital Projects (MCP). This section introduces the concepts related to site selection, layout strategies, activities involved and timing during an asset life-cycle.

2.1 Facility life-cycle and timing of siting and layout activities

The different phases of a MCP and the relative timing for conducting the site selection, facility/equipment layout and layout optimization is illustrated in Figure 1. The review of the effectiveness of the layout as a safeguard needs to be validated during any major changes to the facility operation or during risk revalidations.

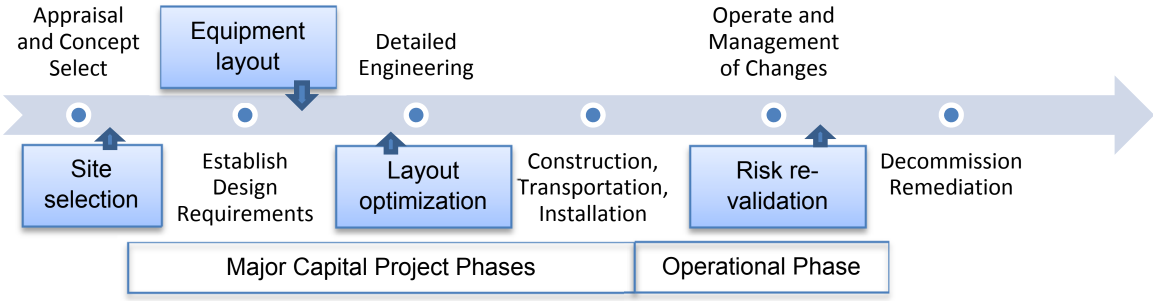

Figure 1: Timing of siting and layout activities – facility life

2.2 Layout philosophy and design strategies

The arrangement of process equipment and buildings can have a large impact on plant economics (Seungho J et. al, 2009). The layout of a facility and equipment is a key driver to ensure the overall safety of workforce and, in some cases, the public. The two key objectives of layout are to minimize the hazards and simplify operation and maintenance.

The design (layout) philosophy shall be to reduce the probability of occurrence and consequences of accidents through location, separation and orientation of areas, equipment and functions. For a facility with primary hazards related to hydrocarbons and flammables, through layout wherever possible:

- Separate hazardous and non-hazardous areas;
- Minimize the possibility of hazardous accumulations and spread of flammable liquids and gases;
- Minimize the probability of ignition;
- Minimize the consequences of fire and explosion and therefore escalation potential;
- Facilitate effective emergency response and provide adequate arrangements for escape and evacuation.

Engagement regarding the layout philosophy with the layout designers and engineering teams is crucial to ensure that these teams are able to independently consider and apply ISD principles during their routine work.

The maintenance strategy shall identify the lifting, handling and storage requirements and the design shall address the requirements for handling and movements without injury to workforce and damage to equipment and environment.

The inherently safer design through layout is relatively straightforward for land-based facilities with limited restriction on land availability and usage. However, for facilities where the real-estate is at a premium (e.g. offshore facilities) the concept of three-dimensional (3D) layout becomes significant.

2.3 Layout reviews and activities

A number of activities to improve layout to make facilities inherently safer should include (i) routine model development reviews, (ii) milestone 3D model reviews with wider stakeholders and (iii) targeted facilitated workshops. It is noted during early phases of MCP design there are hundreds of minor layout decisions that designers make on a routine basis to support ISD principles.

The layout reviews and related activities should aim to address the following:

a) What is the design basis for layout of modules and equipment?
b) What and where are the largest hazards: isolatable inventories; pressures; temperature; process and material properties?
c) What could happen if a loss of control of energy (e.g. chemical, load at height) occurs, escalation?
d) Do releases accumulate due to confinement, congestion, bunding/curbing, plating, decking?
e) What are the safety critical systems and equipment (e.g. flare, relief, firewater, power etc. including emergency response) provided and their relative location to hazards?
f) Where would a release go due to wind, slope or current; dispersion; ventilation or drainage?
g) What the continuous and routine sources of emission (e.g. vent plumes, volatile organic components), sources of discharge, radiation, vibration and noise?
h) Where are the high-activity areas and people located during normal operation and routine maintenance?
i) Who else is at risk: construction, commissioning, turn-around, off-site personnel? Where are they located? How long will they be subjected to exposure?
j) How do people escape? How do they shelter?

3. Layout

To maximize efficiency, plant layout should facilitate the production process, minimize material handling and operating cost, and promote utilization of manpower (Seungho J et. al, 2009). Layout is also a key driver to ensuring the safety of plant personnel. Efficient layout can reduce the probability of occurrence (e.g. vapor cloud) and consequences of accidents (e.g. explosion load) through location, separation and orientation of areas, equipment and functions. This section explains strategies to reduce process risk through layout.

3.1 Segregation

Risk reduction through segregation of hazards from non-hazards is a key strategy considered in facility layout. This is applicable for both the process related equipment, storage, handling area and the location of the normally manned areas (e.g. occupied buildings) and other receptors of interest.

Where feasible, equipment should be segregated by degree of hazard. For example, for an offshore oil & gas facility, locate equipment with the highest potential for release of hydrocarbons as far from control rooms, fire pumps, generators, and living quarters as possible and in areas with good natural ventilation. Typically, on a fully integrated offshore facility, this will result in the wellheads being placed on one end of the facility and the living quarters, control room, and other safe equipment on the opposite and upwind end. The production and gas compression equipment would then be located in the center sections, potentially with fire walls separating them from the wellhead area and from the safe area.

Helidecks are typically located on top of quarters buildings, providing maximum distance between helicopters and the drilling facility and minimizing personnel movements in high hazard areas. For a floating production, storage, and offloading (FPSO) vessel, the bridge and living quarters will typically be in the forward side, the more hazardous modules located in the opposite direction, and the flare would be at the aft side. On some facility designs (i.e., a six-leg jacket design), it is more practical to place the wellheads between the jacket legs and cantilever the compression module over one end and the living quarters over the opposite end. Production equipment and utilities would be located between the other legs, with appropriate fire walls installed as needed.

Figure 2 illustrates a typical offshore platform with sources (flare, vents etc.) and their relative location to the receptors (crane operator, helideck etc.). Hazardous activities, processes and material handling is primarily segregated to hazardous area and buildings, utilities etc. are segregated non-process area. The prevailing wind direction is considered such that any releases and emissions will be transported away from the receptors by wind. For example, the atmospheric vents for flammable or toxic material routed to a safe location (i.e. away from normally manned areas and areas with ignition sources).

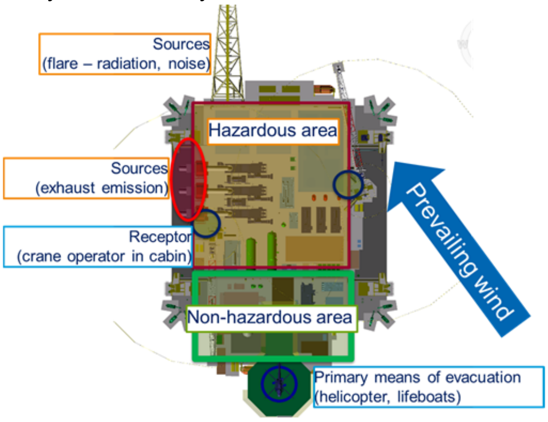

Figure 2: An offshore platform layout

3.2 Orientation

Orientate facilities such that occupied buildings and accommodation modules maximize natural ventilation and are exposed least to hazardous area. Appropriate ventilation, through orientation, can reduce the impact or likelihood of flammable clouds.
Figure 3 illustrates how changing the orientation of a facility by 90o enhanced the natural ventilation by minimizing the blockage due to the buildings placed on the upwind side.

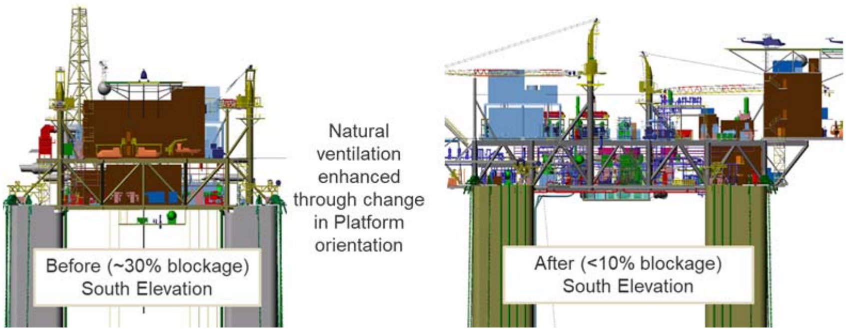

Figure 3: An offshore platform – elevation view with two orientations

Equipment and vessel orientation and related factors should also be considered:

- Locate pressurized cylinders and storage vessels in a secluded area vertically placed with proper fastening and orient their ends away from occupied buildings;
- Orient high pressure process vessels such that projectiles (dish ends) fly away from the platform;
- Align flanges such that releases are away from potential sources of ignition and have minimum impact to buildings and critical equipment;
- Orient rotating equipment, turbine blades and pig receivers so missiles will not impact occupied buildings;
- Orient lifeboats such that wind and current drive the survival craft away from the facility in an event;
- Locate flare and vents such that prevailing winds take emissions away from receptors including turbine intake, helideck and air intakes;
- Locate exit doors of quarters and occupied buildings away from potential hazards and with immediate access to emergency egress routes.

3.3 Separation

For an offshore facility, the layout is largely constrained by the structure or facility boundaries. Options for ensuring the minimum safe separation distances between modules are often limited and at times the requirements can only be achieved by physical barriers such as fire and/or blast walls. Optimizing separation distances to minimize the potential for escalation is a key design strategy.

An example of utilizing quantitative risk assessment (QRA) and three-dimensional modeling for realistic risk analysis of an offshore oil & gas facility to optimize layout during ‘alternate development’ phase is illustrated in Figure 4.

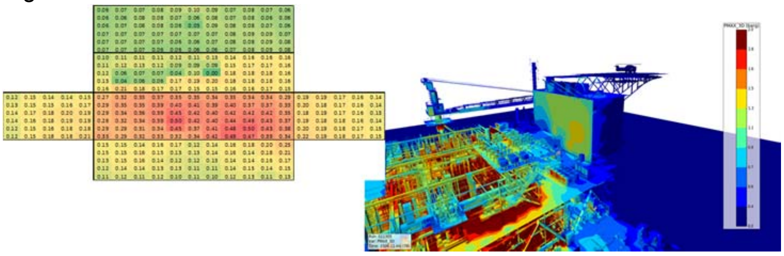

Figure 4: Vapor cloud explosion overpressure load estimation on an offshore platform building

The project mentioned in the example followed a risk-based design decision approach. At 10% engineering progress, a QRA model was established and the consequences were evaluated in detail. The initial risk-based design accident load (DAL) for an occupied building required three walls and floor to be rated for an explosion load exceeding 1 barg. The key driver was identified to be a high-pressure gas compression module in confined location close to the building. The Layout was revised to increase the separation and improve ventilation. Updated analysis estimated a DAL of 0.5 barg on just one wall. This optimization of the layout for risk reduction also provided benefits economically for the project as the total cost and weight of the facility was reduced.
The project also evaluated benefits of separation of decks by fully plating versus grating (allowing vapor, thermal radiation and explosion overpressure migration). The project decided for partial plating primarily for areas handling liquids and protect critical receptors.

3.4 Other considerations for layout optimization

The overall layout development should incorporate safety considerations while providing support for operations and maintenance. Good layout should also consider space for future expansion as well as access for installation, and thereby prevent design rework later (Seungho J et. al, 2009). Some of the design features to be considered during layout design and optimization are given below:

- Design layout for movement and dispersion of dense phase fluids
- Layout to minimize the length and complexity of interconnecting pipework
- Layout design shall consider space requirements for safely operating and maintaining equipment; walkway layout and equipment access shall meet human factors engineering requirements;
- Minimize the need for mechanical handling and hence potential mechanical handling incidents; Hazards from motion and gravity; appropriate lift-paths, laydown and crane hand-shake; All process equipment located beyond area exposed to crane handling and dropped objects
- Subsea layout shall ensure safety during operation and intervention activities; consider drilling & completions operations / activities and incorporate into the subsea layout; Routing of pipelines to avoid potential external interference threats
- Ensure adequate means to reach protected muster from places of work, provisions of evacuating and escaping are provided, and they will be available after the initial event and functioning.
- Layout shall be such that, safety critical equipment, systems and load bearing structure shall be able to function their expected performance after an initial event (e.g. explosion or fire).
- Layout shall ensure potential changes through the asset life and potential additions (or deletion) of process streams, equipment and system and provisions for temporary equipment, buildings during turn-arounds, phased developments etc.

4. Challenges

4.1 Acknowledging layout as a safeguard

Layout as a safeguard is not often listed or credited in risk assessments. As a result, there may be a tendency to over-engineer or rely on other add-on safeguards. This challenge can be addressed through improving awareness (through training, sharing examples) and highlighting benefits of layout safeguard over other engineered safeguard controls. It is recommended to incorporate siting and layout as a safeguard in the list of standard / typical safeguards referred for risk assessments and safeguard stewardships.

4.2 Maintaining layout as a safeguard

Unless maintained as designed and built, layout may not be an effective safeguard. Separation distances and clearances for ventilation are often compromised with scaffolds, temporary equipment and structures. To overcome this challenge, (i) layout needs to be included as an item in the Management of change (MOC) process and (ii) effectiveness of layout as a safeguard needs to be assured through periodic verification activities (such as field visits and comparison with as-built visuals and drawings).

4.3 Limited guidance

The Center for Chemical Process Safety (CCPS) has published guidelines for facility siting and layout (AIChE, 2003). Based on industry practice and standards, they provide guidance for finding an optimal production site and for proper placing of units within the plant with safety as a major consideration. However, the guidelines do not provide a systematic method for plant layout (Nancy et.al., 2014), nor the concept of layout as a safeguard.
A project execution strategy using layout as a safeguard, the design philosophy and the activities mentioned in section 2 can be effectively used for overcoming this challenge in offshore projects.

4.4 Conflicts and trade-offs

Layout optimization is an iterative process and there will always be conflicts; For example, the requirement to maximize separation distances conflicts with the requirement to minimize the length of interconnecting pipe work. The proposed facility layout must be a balance of achieving the best outcome relative to all the factors whilst meeting the physical constraints of the site and equipment.

5. Conclusions

Decisions on facility siting and layout are made during early design engineering phases and such decisions have the highest impact on the inherent risk profile of a MAH facility. This paper demonstrates that through systematic application during facility design, layout can be an effective safeguard and help engineer an inherently safer facility. It highlights the relevance of incorporating site selection and layout strategies as part of project design philosophies and the different activities involved with respect to the facility life cycle. The challenges and the significance of maintaining the functionality of layout and siting as safeguards is explained. The key factors, strategies and examples from projects related to oil & gas projects shared in the paper highlight that the maximum value of layout as a safeguard can only be realized if applied early in the project (before layout is finalized). The overall reduction in risk to personnel and benefits in expenditure have been identified as key drivers for establishing and maintaining layout as a critical safeguard. Therefore, the authors recommend that a systematic approach for effectively utilizing layout through establishing a layout philosophy (including siting and concept selection) and layout reviews should be utilized for MAH MCPs to manage risk.

Acknowledgments

The authors would like to thank Chevron Leadership in Upstream Organization and Energy Technology Company for the opportunity to support the risk reduction initiatives and demonstration of layout as a safeguard.

References

AIChE, 2003, CCPS Guidelines for Facility Siting and Layout, ISBN 978-0-8169-0899-8

API, 2014, API Recommended Practice 2A-WSD Planning, designing, and constructing fixed offshore platform – Working Stress Design, 22nd edition Section 17

ISO, 1998, ISO 13702 Petroleum and Natural Gas Industries - Control and Mitigation of Fires and Explosions on Offshore Production Installations - Requirements and Guidelines

Nair, S. R., 2017, Inherently Safer' – the Concept and its Application in Oil & Gas Sector, International Conference on Safety and Fire Engineering

Nancy Medina-Herrera, Arturo Jiménez-Gutiérrez, Ignacio E. Grossmann, 2014, A mathematical programming model for optimal layout considering quantitative risk analysis, Computers & Chemical Engineering, Volume 68, Pages 165-181

Seungho Jung, Dedy Ng, Jin-Han Lee, Richart Vazquez-Roman, M. Sam Mannan, 2010, An approach for risk reduction (methodology) based on optimizing the facility layout and siting in toxic gas release scenarios, Journal of Loss Prevention in the Process Industries, Volume 23, Issue 1, Pages 139-148