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A quantitative risk analysis approach to port hydrocarbon logistics

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Abstract

A method is presented that allows quantitative risk analysis to be performed on marine hydrocarbon terminals sited in ports. A significant gap was identified in the technical literature on QRA for the handling of hazardous materials in harbours published prior to this work. The analysis is extended to tanker navigation through port waters and loading and unloading facilities. The steps of the method are discussed, beginning with data collecting. As to accident scenario identification, an approach is proposed that takes into account minor and massive spills due to loading arm failures and tank rupture. Frequency estimation is thoroughly reviewed and a shortcut approach is proposed for frequency calculation. This allows for the two-fold possibility of a tanker colliding/grounding at/near the berth or while navigating to/from the berth. A number of probability data defining the possibility of a cargo spill after an external impact on a tanker are discussed. As to consequence and vulnerability estimates, a scheme is proposed for the use of ratios between the numbers of fatal victims, injured and evacuated people. Finally, an example application is given, based on a pilot study conducted in the Port of Barcelona, where the method was tested.

Keywords: Ports; Accident frequencies; Hazardous materials; Hydrocarbon logistics; Quantitative risk analysis

1. Introduction and brief review of the literature

In this paper a method for applying quantitative risk analysis (QRA) to port hydrocarbon logistics is described and discussed. Ports are environments often overloaded with hazardous materials, both in bulk and containerised. Recent HazMat accidents at port terminals include those that occurred in 2004 in Porto Torres, Italy (tanker unloading benzene, two deaths, loss of ship), and in 2003 in Octiabrskaya, Russia (explosion and fire of tanker unloading crude oil, one death), Gdansk, Poland (four killed after the explosion of a petrol barge), and Staten Island, New York (two crew members dead while unloading a petrol barge).

The method here proposed was first devised as part of a Spanish project called FLEXRIS and applied to the premises of the Port of Barcelona, one of the largest ports on the Mediterranean Sea. Though based on a QRA approach [1], this method presents a number of novel features that deserve special consideration.

Over the last few decades much experience has been gained in the field of risk analysis of standard (petro)chemical plants. Now this knowledge is being applied to a wide range of industrial activities involving hazardous material handling, including ports. Nevertheless, few works on the application of QRA to navigational aspects and terminal operations are available. On a European level, this is probably due to the role played by the Seveso II directive [2], which does not affect these environments. But public authorities are beginning to feel concerned about how safe harbours are, not only with regard to land operations but also to the possibility of ship collisions and (un)loading accidents. The Spanish government, in compliance with IMO's *OPRC Convention*[1], has recently issued a decree [3] in which, among other things, port authorities, marine loading

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[1] The International Convention on Oil Pollution Preparedness, Response and Co-operation was issued by the International Maritime Organization in

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Nomenclature

d	pool diameter (m)
f	frequency (year^{-1})
f_a	frequency of a ship–land collision while a tanker is manoeuvring near a berth (operation^{-1})
f_b	frequency of a ship–ship collision while a tanker is (dis)charging at a terminal (operation^{-1})
F_b	frequency of a ship–ship collision while a tanker is (dis)charging at a terminal, expressed per unit time and per ship passage (operation^{-1} passage^{-1})
f_c	frequency of a ship–land collision, for a tanker moving through the port (operation^{-1})
f_d	grounding frequency, for a tanker moving through the port (operation^{-1})
f_e	frequency of a ship–ship collision, for a tanker moving through the port with another moving ship (operation^{-1})
f_f	frequency of a ship–ship collision, for a tanker moving through the port with a moored vessel (operation^{-1})
$f_{HF,l,m}$	frequency of a minor spill due to hull failure for a ship moving through the port (operation^{-1})
$f_{HF,l,M}$	frequency of a major spill due to hull failure for a ship moving through the port (operation^{-1})
$f_{HF,p,m}$	frequency of a minor spill due to hull failure in the proximity of (un)loading berth (operation^{-1})
$f_{HF,p,M}$	frequency of a major spill due to hull failure in the proximity of (un)loading berth (operation^{-1})
m	number of products bunkered in the port
n	number of hydrocarbon products traded in the port
p_m	probability of a minor spill, given the external impact on the hull
p_M	probability of a major spill, given the external impact on the hull
Q_f	release flow rate (kg/s)
R	individual risk (victims person^{-1} m^{-2} year^{-1})
RF	lethality function (victims person^{-1} m^{-2})
T	ship traffic (passages/h)
Δt	duration of (dis)charge (h)
x, y	Cartesian coordinates
x_D	fraction of double-hulled tanker traffic
x_S	fraction of single-hulled tanker traffic
y'	burning rate (kg m^{-2} s^{-1})
θ	wind direction (°)

Subscripts

p_i	product i
b_j	berth j

terminals and shipyards are required to produce a contingency plan for accidental marine hydrocarbon pollution, including a study of the effects of possible spills and of their evolution.

In view of these facts, a method is needed to standardise risk assessment in port settings. We feel that this structured procedure will help port system stakeholders (especially port authorities and hydrocarbon terminals) to optimise the performance of their investments in the fields of prevention and safety, by helping them to reduce the most significant risks. For example, newly projected terminals might be located by taking into consideration losses due to accident scenarios. The method devised allows port authorities to build an objective basis for making decisions about the conditions to be required of hydrocarbon terminal dealers, in order to guarantee safety.

Insights on different kinds of risk assessment for HazMat handling at port terminals can be found in the following:

- Rao and Raghavan [4], Thomas [5] and Hartley [6], who present the use of risk indexes specifically devised for port areas;
- Kite-Powell et al. [7], who attempt to build a risk assessment tool based on historical data for US ports;
- Trbojevic and Carr [8], on the subject of safety management systems (with several examples of risk assessment techniques);
- Cunningham [9], who provides a demonstration of a risk matrix;
- Ronza et al. [10], on simplified event trees for port accidents;
- Darbra et al. [11], who provide a historical analysis of accidents in harbours.

Egidi et al. [12] briefly explain how they dealt with the problem of assessing HazMat accident risk at a sea-terminal, while recognising the scarcity of literature on this topic. Several risk assessment reports, made available to the public via the Internet, proved to be a valuable source of information. Some of these reports were taken into account while carrying out the present project [13,14], despite the fact that they are not actually complete QRAs. The *Canvey Reports* [15,16] were the first significant contribution to industrial port environment QRAs, and they are still relevant today. What these works lack, however, is an attempt at standardising the process of risk assessment of navigation and (un)loading operations for a generic port/terminal. This is what has been done in this project in the case of hydrocarbons, with a special regard to accident frequency estimation.

1990. The 1998 OPRC re-issue is now the principal legislation on counter pollution from a harbour authority and oil handling facility perspective.