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# Risk Assessment of Port Manoeuvres of a Chemical Tanker Vessel

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ABSTRACT: The development of smart port systems and autonomous navigation is related to the growing interest in the systemic approach to risk assessment of port operations especially for the vessels transporting dangerous cargo. The paper presents the general risk model of port manoeuvres of a chemical tanker vessel. The risk model is based on Bayesian influence diagram allowing to determine the risk dependent on the decisions made with respect to the applied safety options. The conclusions are based on real life near miss examples and discussion of experienced Ship Masters.

## 1 INTRODUCTION

The safety of port manoeuvres of chemical tankers is particularly important due to the risks associated with the transport of dangerous cargoes.

Due to the features of dangerous cargo onboard a margin for unnecessary risk is much lower in comparison to ships carrying other cargoes. The gravity and consequence of an accident is much higher in comparison to other vessels due to character of cargo onboard which can be:
– flammable/volatile/explosive,
– corrosive,
– self-reacting ,
– reacting with other substances (e.g. water )
– involving serious pollution in case of spill/release.

The explosion of a chemical tanker as a result of a violent self-reaction of styrene monomer shown in Fig. 1 illustrates the scale of hazards associated with cargo on chemical tankers.

Figure 1. Chemical tanker explosion due to vigorous self-reaction of Styrene Monomer [12] .

The usual consequences of an accident, such as damage to the ship and port infrastructure, in this case can lead to further consequences, usually not expected for other types of vessels - fire, explosion, environmental pollution or poisoning and can be fatal.

Ports and terminals determine the precautions for chemical tankers operation. The international regulations and guidance for safe carrying hazardous chemicals at sea are provided by a number of conventions and codes i.e.: the consolidated editions of international conventions Safety of Life at Sea (SOLAS) and International Convention for the Prevention of Pollution from Ships (MARPOL – 73/78), International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk (IBC Code), Code for the Construction Equipment of Ships Carrying Dangerous Chemicals in Bulk (BCH Code), International Safety Guide for Oil Tankers and Terminals (ISGOTT), Tanker Safety Guide (Chemicals), Ship to Ship Transfer Guide (Petroleum), Safety in Oil Tankers, Safety in Chemical Tankers, The International Maritime Dangerous Goods (IMDG) Code, Supplement to IMDG Code Medical First Aid Guide for Use in Accidents Involving Dangerous Goods (MFAG) and Emergency Response Procedures for Ships Carrying Dangerous Goods Guide (EmS), Ship Oil Pollution Emergency Plan SOPEP, Clean Seas Guide for Oil Tankers, FOSFA (for Oils, Seeds and Fats), Prevention of Oil Spillage through Cargo Pumproom Sea Valves, Chemical Hazards Response Information System manual (CHRIS Guide USCG), Chemical Data Guide for Bulk Shipment by Water (Condensed CHRIS), Material Safety Data Sheet (MSDS) for particular cargo.

The ship master is responsible for understanding and complying with local regulations.

The priorities of precautions that are taken by chemical tankers before, during, and after cargo operations have been previously studied by Arslan [3], who proposed to use AHP (Analytic Hierarchy Process) method. The study presented in this paper concentrates on the safety of port manoeuvres performed by a chemical tanker close to the terminal. The ship-port-environment system has been considered in the risk assessment study and formal approach has been used in the development of a risk model, including: hazards identification, possible accidents related to the identified hazards, their probability, consequences, risk prevention and risk reduction options [7].

Taking into account the high level of uncertainty, probabilistic knowledge about possible accidents or knowledge based on experts opinions, the Bayesian influence diagram was proposed for modelling the risk [1,4].

The proposed general model can be further developed with respect to its implementation in smart port systems, autonomous integrated transport infrastructure [8,14] and control systems of autonomous ships [10].

The examples of dangerous and near miss situations during port manoeuvres are presented. The risk control options are analysed from the point of view of the experienced ship master of a chemical tanker.

## 2 PORT OPERATIONAL LIMITATIONS

### 2.1 *Safe manoeuvring space*

With a ship size similar to the size of the design ship for a given port, safe manoeuvring space also depends on the dimensions of the berths and locks with limited access for tugs. Vessel size can be just on the limit for compulsory use of tug or tugs and it may also leave some hesitation in view of Ship Masters decision to take a tug or not. This is related to commercial pressure associated with demanding and competitive market in order to reduce idle days of ship in operation. In this case, the human factor is of great importance [2].

Most common factor for compulsory use of tug imposed by port authorities will be the size of a ship, whether or not dangerous cargo is onboard and whether the weather conditions, mostly wind force, are within port limitations.

The manoeuvring areas limited horizontally by narrow channels, berths and jetties too small to accommodate the ship, tight turning areas, narrow locks without fenders and small ratio of the water depth to the ship's draught results in a very limited UKC (under the keel clearance) when approaching and mooring to the pier.

An example of a chemical vessel with corrosive Sodium hydroxide solution cargo onboard, leaving a small (23 meters wide compared to 19.8 m ship breadth) Runcorn lock from Runcorn channel (England) and entering bigger lock, stern first, port side alongside, in order to get into Eastham dock, is presented in Fig. 2

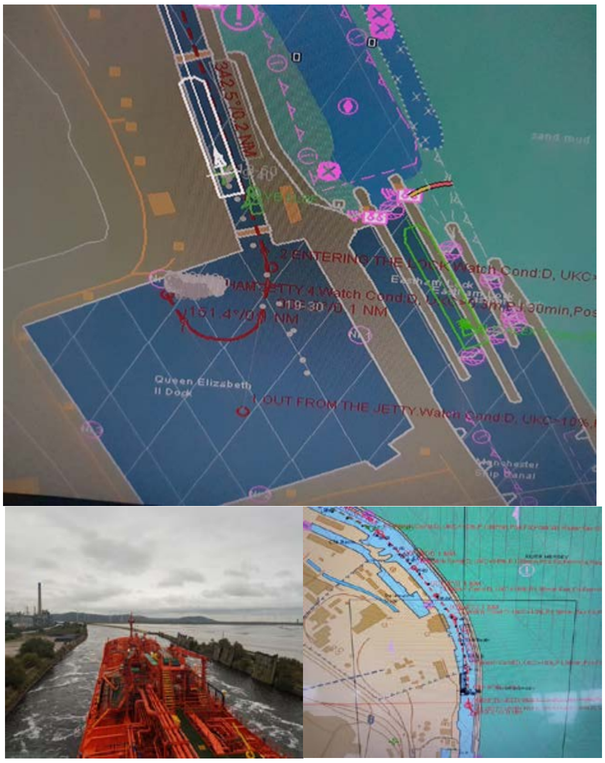


Figure 2. Runcorn – Eastham vessel shifting during the night – upper figure, proceeding astern to Runcorn jetty with 2 tugs on narrow bend, kicks ahead needed with rudder in purpose to correct drift from the wind. ( cargo onboard – Sodium hydroxide solution, cat Y, corrosive).

The local knowledge about water levels is required in order to fulfil UKC margins and safety requirements. In case that a vessel is not complying with regular company requirements (e.g. UKC=10 % of dynamic draft), thorough risk assessment must be performed and decision must be consulted with DPA (Designated Person Ashore).

At times it is better to take less cargo onboard during loading then later wait few days for water level to rise just a few centimetres, what happens for example in Swedish ports, with water level fluctuations, it may be recommended to leave few centimetres allowance during loading stage in port for possible drop of water level on arrival at discharge port.

### 2.2 *Deck operations affecting navigation*

Due to busy and complex character of cargo handling activities on chemical tanker, some activities on deck may still be performed even during pilotage stage of navigation.

Mopping, steaming, checking of cargo tanks, ventilation of tanks and works on deck may be still present just before mooring. However some activities are strictly forbidden in ports when the pilot is onboard. For example ventilation of toxic and smelly cargoes (e.g. containing benzene) which can be easily smell by pilots. These operations shall be stopped at this stage.

In case of steaming, in some conditions this operation may affect maneuvering by limiting Ship Master visibility on approach to a jetty. In this case steam shall be stopped.

Steaming of mooring systems and equipment in case of sub-zero conditions (e.g. Finland and Sweden during winter season) shall be done well in advance.

Tank cleaning operations shall be limited in confined waters to a minimum in purpose to reduce a risk of black out. Power consumers like bow thrusters shall have priority.

## 3 GENERAL RISK MODEL OF PORT MANOEUVRES OF A CHEMICAL TANKER VESSEL

In the ship-port-environment anthropo-technical systems both the technical aspects and human factors are considered [2, 6, 13, 15]. The factors considered in the hazards identification and risk reduction options processes are related to the ship, port and environment.

### 3.1 *Factors considered in hazards identification*

The factors considered in hazards identification related to technical aspects are as follows.

Factors related to the ship:
- chemical and physical properties of the ship's cargo,
- technical condition of ship hull construction,
- technical condition of ship cargo systems,
- technical condition of ship handling systems,
- technical condition of the deck equipment – mooring, towing, emergency towing and anchoring systems,
- age of the ship,
- availability of ship handling aid systems,
- communication with the terminal,
- emergency equipment.

Factors related to the port:
- communication with the terminal,
- reliable weather forecast,
- current and tide information,
- pilotage,
- towing assistance,
- technical condition of cargo handling facilities,
- technical properties and condition of berthing facilities, fendering and mooring systems,
- decision support systems: docking systems, pilotage aid system,
- dangerous operations carried out close to the vessel,
- availability of emergency services:
  - firefighting services,
  - emergency towing services,
  - pollution response services,
  - emergency medical services.

Factors related to the environment:
- shallow water conditions,
- wind,
- current,
- waves,
- fog,
- ships' congestion in the port.

Human factors related to the following ship personnel:
- Ship Master,
- Officer of Watch,
- deck personnel.

Human factors related to the following ashore and port personnel,
- tug boat master,
- port pilot,
- VTS operator,
- harbour master office operator,
- berth personnel,
- designated person ashore.

### 3.2 *Risk model of port manoeuvres of a chemical tanker*

The risk model developed in form of the Bayesian influence diagram includes decisions made by ship personnel with respect to use of risk reduction options having impact on the probability of events, cost of the risk reduction options and consequences related to the identified accidents.

The events in the model are random variables represented by the nature nodes in the directed, acyclic graph. The arcs of the graph show the causal relationships between the dependent nodes. The conditional dependencies between the linked events are represented by probability tables assigned to the nodes.

Based on the conditional independence of variables and the chain rule, Bayesian belief network allows to determine the joint probability distribution of the variables.

The decision nodes represent the risk control options and their costs. The utility nodes represent risks of possible accidents, including costs related to their consequences.

The events – nature nodes of Bayesian influence diagram considered in the general model are presented in Tables 1-3.

Table 1. Definition of the events – berthing, mooring, moored ship and unberthing

| Node | Description of probability | States |
|---|---|---|
| Berthing | Probability of an accident during berthing | Safe<br>ALARP<br>Unsafe |
| Mooring | Probability of an accident during mooring operations | Safe<br>ALARP<br>Unsafe |
| Moored Ship | Probability of an accident related to the moored ship | Safe<br>ALARP<br>Unsafe |
| Unberthing | Probability of an accident during unberthing | Safe<br>ALARP<br>Unsafe |

Table 2. Definition of events - ship and port technical conditions

| Node | Node description | States |
|---|---|---|
| Ship | Probability of failure on board ship | Safe<br>ALARP<br>Unsafe |
| Port | Probability of failure in port | Safe<br>ALARP<br>Unsafe |

Table 3. Definition of events – external conditions

| Node | Node description | States |
|---|---|---|
| Wind | Probability of a dangerous wind speed and direction | Yes<br>No |
| Current | Probability of a dangerous current speed and direction | Yes<br>No |
| Passing vessel | Probability of a dangerous impact of a passing vessel | Yes<br>No |

Table 4. Definition of risk reduction options – decision nodes

| Node | Node description | States | Cost keuro |
|---|---|---|---|
| Tug boat | Decision of tug boat assistance | Yes<br>No | 1-1.5 |
| Leaving port | Decision on emergency leaving the port | Yes<br>No | 103–105 |
| Mooring lines | Decision on application of additional mooring lines | Yes<br>No | |

Risk reduction options are related with decisions to employ tug boats, leave the port and use additional mooring lines. The costs of tug assistance during berthing and costs related to emergency leave can be estimated for the particular port and vessel [5].

For example the cost of slight impact with jetty is up to 200 keuro e.g. touching dolphin as a result of a failure to shift controls from central console to bridge wing. Cargo spill , pollution can cause severe financial loss – millions of euro, loss of reputation of a company, in severe case could face bankruptcy. Fire can cause severe financial loss – millions of euro.

The casualties mainly relate to accidents during mooring operations, such as broken mooring lines or structural damage to mooring equipment. There is also a risk of an accident in the event of a collision or collision with another object or vessel.

The definition of decision nodes of Bayesian influence diagram are presented in Table 4.

The utility nodes of Bayesian influence diagram presenting the risk of possible accidents are presented in Table 5.

Table 5. Risk of possible accidents – utility nodes

| Node | Node description |
|---|---|
| RP | Risk of port facility damage / delay in port operation |
| RI | Risk of people injuries |
| RF | Risk of fatalities |
| RE | Risk of environment pollution |
| RS | Risk of ship damage |

The most important for development of the risk model is the design of the network structure and then input of the dependent probability values for the defined nodes which allows for calculations of the joint probability distribution for the nodes. The model presented in the paper was developed using a commercial tool for Bayesian belief network development - Hugin Researcher - the computer program with graphical interface, compiler and system for design and use of knowledge base.

Bayesian network allows to dynamically assess the probability of accidents. The information about the occurrence frequency of the top event propagates backwards through the network, changing the probability of the primary events [9].

In the presented network, in the events of ship damage or port facility damage, risks are calculated on the basis of the joint probability distribution of accidents and their costs dependent on states of the events which can be negligible, minor, moderate, major or catastrophic. In case of further results of ship damage and port facility damage accidents like fire, explosion and toxic leakage the consequences can be personnel injuries, fatalities and environment pollution.

The Bayesian risk model of port manoeuvres of a chemical tanker is presented in Figure 3.

## 4 RISK CONTROL OPTIONS OF POSSIBLE ACCIDENTS DURING PORT MANOEUVRES

The risk control options include proper exchange of information between the vessel and terminal before berthing, proper weather information, tug assistance during navigation in difficult to manoeuvre and dangerous areas, tug assistance during berthing, unberthing, emergency port leave and proper prediction and control of mooring forces [3].

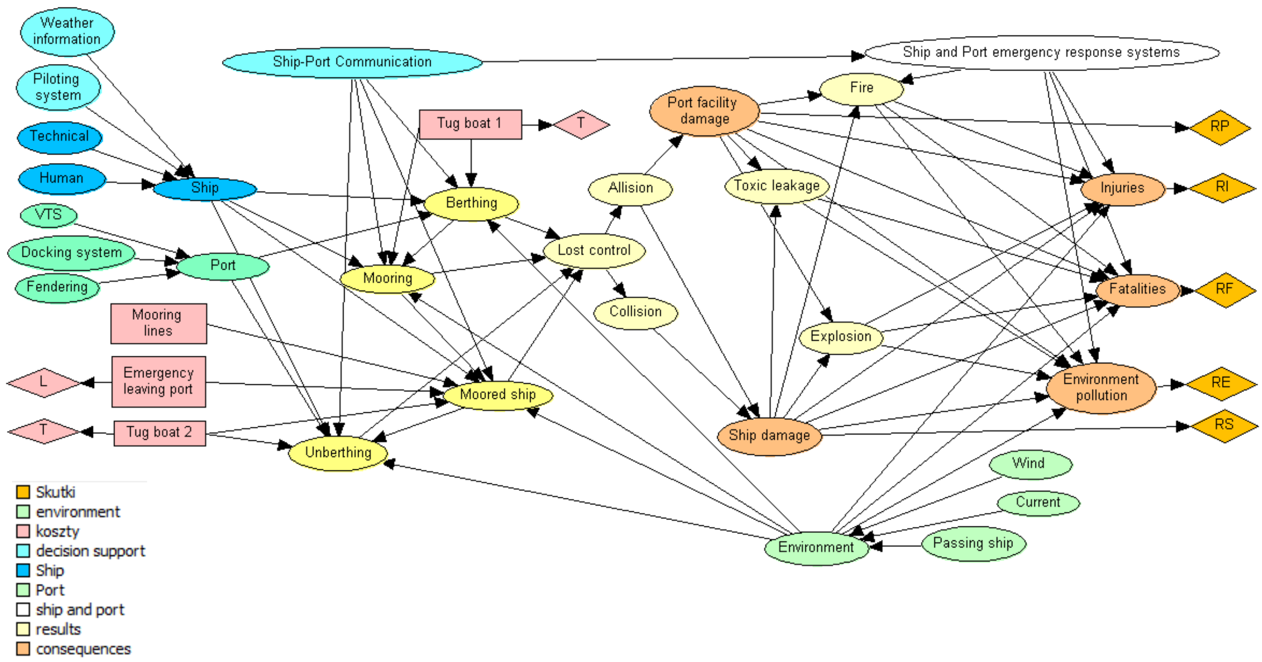


Figure 3. Bayesian risk model of port manoeuvres of a chemical tanker.

A layout, access and dimensions of approach area relative to own ship and port itself with its arrangements and aids must be safe at every stage of approach and mooring.

With modern commercial pressure Master must pay attention that a port of call chosen by a charterer fulfils all criterions and all information about port and weather conditions and that they are easily accessible and comprehensive well in advance.

Master has overriding authority to refuse calling a port if in his judgement it is not safe for navigation. For example when not enough room is provided during turning vessel in narrow waters with limited UKC. Master may also refuse entering port if there is no tug boat provided on demand of the Master as for some ports, notice for a tug boat is long and a tug must arrive from another port nearby.

### 4.1 *Tug assistance*

Tug assistance is an effective measure of reducing risk in restricted waters and port approaches. In some ports due to horizontal (tight bends, narrow channels) and vertical (UKC) limitations tug assistance is compulsory and tug is made fast before entering rocky and narrow fairway. Tug boat is usually connected but idle (Fig. 4).

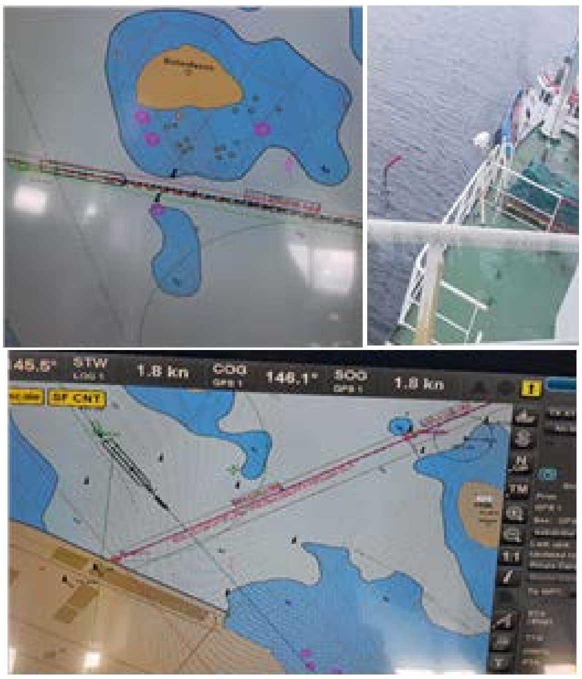

Figure 4. Tug assistance near rocky bottom with limited horizontal and vertical allowance.

### 4.2 *Mooring forces prediction*

Chemical tanker should be equipped with modern winches providing tension and storage drums with capacities equivalent to her size, displacement and designed for expected weather conditions during her lifetime. A brake of a winch shall be properly adjusted to rope's SWL with regular brake tests performed onboard (Fig. 5), with the rendering point properly set and brakes adjusted with use of torque wrench (Fig. 6).

Figure 5.Winch brake test and calibration performed on chemical tanker.

Figure 6. Torque wrench used for mooring in purpose to apply correct force on a brake related to SWL of mooring rope.

When this is done, before a rope brakes (possibly causing damages and fatalities), a properly adjusted brake will slack a rope avoiding parting of a rope. A proper estimation and marking of snap back zones is needed onboard chemical tankers in order to avoid serious injuries cause by parting ropes.

A mooring lines number and service meaning quantity and orientation of ropes, shall take into account:

- loading condition of a ship (windage, inertia, underwater section area) in case of currents,
- wind speed and direction relative to ship's windage area – present and predicted,
- speed and direction of current,
- special weather conditions like high swell (e.g Portuguese ports like Sines ) requiring higher number of ropes and spare ropes to be ready in case of breaking,
- traffic conditions and passing-by vessels (deeper draft vessels when going at higher speeds may create moored ship surge, sway and yaw which may break mooring ropes [10].

### 4.3 *Emergency procedures*

An example of emergency procedure for so called 'break away from jetty ' shall be well known and displayed among other contingencies. Engineers shall be informed about possible adverse weather conditions and possible need for power on short notice. A minimum number of crew should be always onboard during port stay.

Break away from jetty procedures should be trained periodically. An example of a near miss during unmooring on Thames river – under strong current when the aft spring fail to let go is presented in Fig. 7.

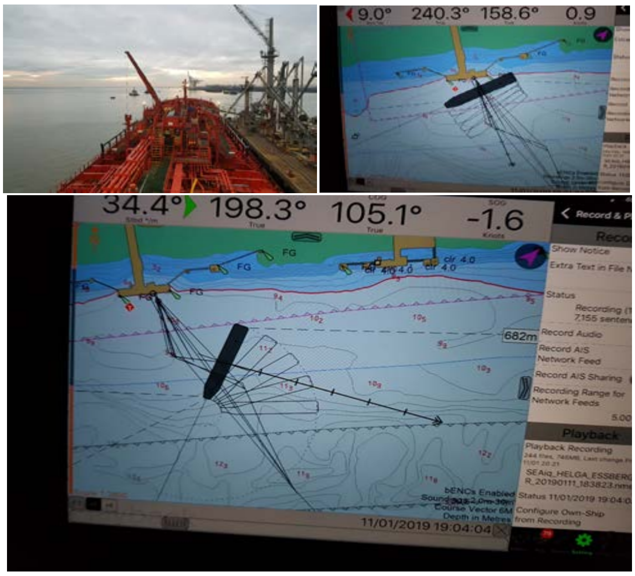


Figure 7. Example of a near miss during unmooring under strong current.

## 5 CONCLUSIONS

The age of the fleet worldwide as a pursuit for savings is caused by commercial pressure. However we need to mention that most Oil Majors - chemical companies have a limit of 20 years for chemical tanker but shipowners are constantly trying to push the limit up to 25 years as it has to be admitted that with systematic and well planned maintenance system it is possible to keep vessel suitable for busy trade for few years more. In this case, it is particularly important to analyse the risk of possible failures and their impact on the occurrence of accidents.

The risk model proposed in the paper can be implemented in decision support tools which can be used by the ship owner, ship master, vessel traffic services or harbour master, planning the port operations.

The implementation of Bayesian network helps to dynamically assess the system's safety and to predict probability and the risk of accidents.

## ACKNOWLEDGEMENT

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