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Analysis of the risks related to the logistics of the Hazardous Materials

Presented by: **Abdellatif SOUSSI**

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Pr. El AMARTI Ahmed	**Faculty of Sciences, UAE, Tetouan**	**President**
Pr. El MOUTCHOU Brahim	**Faculty of Sciences, UAE, Tetouan**	**Rapporteur**
Pr. NACHITE Driss	**Faculty of Sciences, UAE, Tetouan**	**Rapporteur**
Pr. DRAOUI Khalid	**Faculty of Sciences, UAE, Tetouan**	**Examiner**
Capt. AL MIYS Jaouad	**HTT SA, Port Tanger Med, Tangier**	**Invited**
Pr. BERSANI Chiara	**University of Genoa- Italy**	**Co- Supervisor**
Pr. SEGHIOUER Hamid	**ENSA, UAE, Tetouan**	**Co- Supervisor**
Pr. SACILE Roberto	**University of Genoa- Italy**	**Supervisor**
Pr. BOUCHTA Dounia	**Faculty of Sciences, UAE, Tetouan**	**Supervisor**

Dedication

I dedicate this thesis in order to:

My dear parents for their prayers and sacrifices ...

My dear sisters and brothers

My dear friends

All who knows me, etc. ...

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LIST OF BBREVIATION

ADR	European Agreement Concerning the International Carriage of Dangerous Goods by Road
ALARP	As Low As Reasonable Practicable
ALOHA	Area Locations of Hazardous Atmospheres
AMDEC	Analysis of Failure Modes Effects and Consequences
API	American Petroleum Institute
ASCE	American Society of Civil Engineers
ATSs	Accident Test Sites
BLEVE	Boiling Liquid Expanding Vapor Explosions
CAMEO	Computer-Aided Management of Emergency Operations
CCPS	Center for Chemical Process Safety
CLP	Classification and Labelling of chemicals Products
COTIF	Convention concerning International Carriage by Rail
CRP	Emergency Response Guidebook
DG	Dangerous Goods
ERG	Emergency Response Guidebook
ET	Event Tree
ETA	Event Tree Analysis
GHS	Globally Harmonized System
GIS	Geographic Information System
GPM	Gaussian Plume Mode
HACCP	Hazard Analysis Critical Control Point
HAZOP	hazard and operability study
HCP	Haut Commissariat au Plan
HGM	Heavy Gas Model
HM	Hazardous materials
HMR	Residual Hazardous Materials
IATA	International Air Transport Association
IDHL	Immediately Dangerous to Life or Health
IE	Initiating Event
IMDG	International Maritime Dangerous Goods

IMO	International Maritime Organization
IR	Individual Risk
ITOPF	International Tanker Owners Pollution Federation
LOC	Level of Concern
LPG	Liquefied petroleum gas
MTBE	Methyl tert-butyl ether
MTP	Med Tangier Port
NOAA	National Oceanic and Atmospheric Administration Office of Response and Restoration
OTIF	Intergovernmental Organization for International Carriage by Rail
PHO	Probability of Hazmat Outcome
POIs	Point of Interests
PRAT	Proportional Risk-Assessment Technique
PWS	Probability for Weather Stability
QRA	Quantitative Risk Assessment
REMPEC	Regional Center for Emergency Response to Accidental Marine Pollution
RID	Regulation concerning the International Carriage of Dangerous Goods by Rail
SME	Small and Medium Enterprises
SSD	Spill Size Probability
TDG	Transport of Dangerous Goods
TMSA	Tanger Med Special Agency
UVCE	Explosion of Unconfined Vapor Cloud
VCE	Vapor Cloud Explosion
VTS	Vessel Traffic Service
WPP	White Petroleum Products
WRA	Weighted Risk Analysis

Résumé

Le Transport de Marchandises Dangereuses (TMD) est une activité génératrice de risques en raison de la dangerosité intrinsèque des produits considérés qui peuvent, suite à un accident dans le cadre de cette activité, provoquer des effets graves sur l'environnement, les biens et les personnes (effets toxiques, thermiques, de surpression, de pollution…). L'activité TMD se décompose en trois phases : le transport, la manutention (chargement/déchargement) et le stockage.

Afin de comprendre les sources et les causes des risques générés par l'activité TMD au Maroc, nous avons fait une étude sur l'état d'art en ce qui concerne les matières dangereuses (MD) au sein du pays. Cette étude porte sur une enquête concernant les choix logistiques reliés aux matières dangereuses et adressée aux entreprises utilisant, fabriquant, stockant et/ou transportant des MD. Les résultats de l'enquête permettront :

- de positionner l'entreprise par rapport aux autres entreprises qui utilisent ou produisent des MD ;
- de mieux comprendre le niveau de respect de l'ensemble des réglementations appliquées aux MD ;
- d'identifier les besoins par rapport aux choix logistiques en vue de proposer des outils de gestion adaptés ;
- d'aider à l'élaboration des guides qui répondent aux besoins concernant les réglementations MD et les critères de sélection de sous-traitants ainsi que la gestion de leurs contrats.

Par ailleurs, nous avons enchainé par une étude de cas dont le but est de faire une analyse exhaustive sur les risques liés notamment aux (TMD) dans la région de Tanger- Tétouan-Al Hoceima afin de définir des scénarios d'accidents et pouvoir établir une méthode efficace de gestion. La problématique de ce travail consiste donc à évaluer le niveau de risque dans les zones concernées par le transport des matières dangereuses.

Pour approcher cet objectif, on a procédé par une analyse quantitative des risques "Quantitative Risk Assessment (QRA)". Cette analyse est une méthodologie qui estime quantitativement le risque dans le transport de matières dangereuses en associant les conséquences des incidents et l'estimation des fréquences.

La méthodologie QRA dédiée au transport routier de matières dangereuses est une approche simplifiée comprenant :

- L'analyse de fréquence réalisée en considérant des schémas d'arbres à événements présélectionnés pour les produits dangereux.
- L'analyse des conséquences basée sur la méthode innovante Short Cut & et le logiciel ALOHA (Areal Locations Of Hazardous Atmospheres) permettant de calculer les zones d'impact. En outre, des mesures de risques sociétales et des courbes FN ont été réalisées pour comparer le risque de transport d'essence, GPL (Butane & Propane) et du Chlore par camion-citerne couvrant deux voies alternatives du port Tanger Med à Tanger et du Port Tanger Med à Tétouan au nord du Maroc.

Les travaux de recherche de cette thèse ont été élargis pour aborder les risques dans le transport maritime des MD. Dans ce contexte, une étude détaillée a été réalisée sur le transport maritime de produits pétroliers dans la zone du Détroit de Gibraltar qui supporte un volume de trafic maritime important en tant que canal principal de liaison de navigation entre l'océan atlantique et la mer méditerranée. Cette étude repose sur un modèle lagrangien de déversements, volontaires ou accidentels, d'hydrocarbures. Ce modèle permet la prévision de la zone d'impact de la marée noire et ces trajectoires à la surface de la mer. L'estimation de la probabilité d'accident et l'analyse des conséquences sont basées sur des données statistiques, sur l'occurrence d'un accident de déversement d'hydrocarbures, sur la probabilité des différentes tailles de rejet et sur la probabilité conjointe de la vitesse et de la direction du vent.

L'ampleur des risques pour le littoral méditerranéen a été évaluée par la détermination du temps requit par la marée noire pour toucher les côtes en des points sensibles. Pour ce faire, on suppose qu'un éventuel accident de déversement de pétrole a eu lieu sur l'un des sites sélectionnés et localisés sur les routes maritimes typiques. Les résultats de cette étude peuvent être utilisés pour soutenir un processus décisionnel et/ou comme une base pour des analyses plus approfondies.

Enfin, et pour illustrer l'aspect appliqué de nos travaux, nous avons effectué, en collaboration avec le terminal pétrolier du Port Tanger-Med Maroc, une étude concernant les risques dans la manipulation et le stockage des produits pétroliers. Il s'agit d'une approche systématique pour analyser les séquences et les inter-relations dans des incidents ou des accidents potentiels, en tenant compte de la chaîne logique, des événements dangereux critiques et de leurs conséquences indésirables. Le modèle permet de quantifier les risques en établissant la base d'une approche basée sur la performance pour l'évaluation des normes de sécurité.

Introduction

Preface and objectives

Today, the number of industrial enterprises producing, using, storing and transporting hazardous materials is constantly increasing worldwide. This growth is linked to the progressive demand in various sectors, which makes our world riskier because of the nature and diversity of the dangerous events that may occur.

The risks incurred by the hazardous materials transport activity, in case of the occurrence of an incident that may occur and have serious consequences for persons, the environment, property, a fire as an example accompanied by a release of toxic smoke, pollution of the soil and / or water, it can lead in case of non-control of the fire or the reactivity of the goods transported to an explosion. To this purpose, it is essential to protect the health and safety of personnel and to preserve the environment from any deterioration related to the risks incurred by the Transport of Dangerous Goods (TDG) business, which presents important issues for population, state and highly urbanized areas

The aim of this thesis is to propose a systemic approach to risk assessment, taking into account in a global way the risks related to hazardous materials throughout the logistics chain (transport & storage).

The approach consists of using the modeling and simulation techniques of an accident, to understand the consequences generated in the various scenarios in the event of the occurrence of a hazardous materials accident. This approach will allow the presentation of an industrial safety reasoning method based on actual case studies, rather than a detailed analysis of how to prevent and protect a given hazard.

In the process of assessing the technological risks associated with the Transport of Dangerous Goods (TDG), the essential step is the evaluation of the risk intensity when an accidental event occurs, which is to quantify the risks involved. effects or impacts, in order to respond quickly and prioritize relief actions for the protection of the population and the environment.

The assessment of the intensity of a technological risk can be carried out using an effects model, capable of estimating the effects induced by the hazardous phenomenon from a quantitative point of view, in order to determine the geographical area of the hazard where the intensity of the risk is deemed too high.

In this context, the first issue addressed in this thesis is to assess the level of risk of hazardous goods transport areas for both road and marine modes of transportation, while the second issue of assessing risks in an industrial facility fixed.

Summary

The Transport of Dangerous Goods (TDG) is a risk-generating activity because of the intrinsic danger of the products considered, which can, following an accident in this activity, cause serious effects on the environment, property or to the persons (toxic, thermal, overpressure, pollution ...). The TMD activity is divided into three phases: transport, handling (loading / unloading) and storage.

In order to understand the sources and causes of the risks generated by the TDG activity in Morocco, we did a study on the state of art with regard to hazardous materials (HM) within the country. This study is based on a survey of logistical choices related to hazardous materials and addressed to companies using, manufacturing, storing and / or transporting HM. The results of the survey will allow:

- position the company in relation to other companies that use or produce HMs;
- better understand the level of compliance with all regulations applied to HMs;
- identify needs in relation to logistics choices in order to propose adapted management tools;
- assist in the development of guides that meet the requirements for MH regulations and subcontractor selection criteria and the management of their contracts.

In addition, we have followed up with a case study whose aim is to make a comprehensive analysis of the risks related to (TDG) in the region of Tangier-Tetouan-Al Hoceima in order to define accident scenarios and be able to establish an effective method of management. The problematic of this work is therefore to assess the level of risk in the areas concerned by the transport of hazardous materials.

To achieve this goal, a Quantitative Risk Assessment (QRA) was conducted. This analysis is a methodology that quantitatively estimates the risk in the transport of hazardous materials by combining the consequences of incidents and the estimation of frequencies.

The QRA methodology for road transport of hazardous materials is a simplified approach that includes:

- Frequency analysis performed considering preselected event tree schemes for hazardous products.
- The impact analysis based on the innovative Short Cut & method and ALOHA (Areal Locations of Hazardous Atmospheres) software for calculating impact zones. In

addition, societal risk measures and FN curves were performed to compare the risk of transporting gasoline, LPG (Butane & Propane) and tanker-borne chlorine covering two alternative routes from Tangier Med port to Tangier and Port Tanger Med in Tetouan in northern Morocco.

The research work of this thesis has been expanded to address the risks in maritime transport of HMs. In this context, a detailed study was carried out on the maritime transport of petroleum products in the Strait of Gibraltar area, which supports a large volume of maritime traffic as the main navigation link between the Atlantic Ocean and the Mediterranean Sea. This study is based on a Lagrangian model of spills, voluntary or accidental, of hydrocarbons. This model allows the prediction of the impact zone of the spill and these trajectories on the sea surface. The estimate of the probability of accident and the analysis of the consequences are based on statistical data, on the occurrence of an oil spill accident, the probability of different rejection sizes, and the joint probability of wind speed and direction.

The magnitude of the risks for the Mediterranean coast was assessed by determining the time required by the oil spill to touch the coast at sensitive points. To do this, it is assumed that a possible oil spill accident occurred on one of the selected sites and located on the typical shipping lanes. The results of this study can be used to support a decision-making process and / or as a basis for further analysis.

Finally, and to illustrate the applied aspect of our work, we carried out, in collaboration with the oil terminal of the Port Tanger-Med Morocco, a study concerning the risks in the handling and the storage of the petroleum products. This is a systematic approach to analyzing sequences and interrelations in potential incidents or accidents, taking into account the logical chain, critical hazard events and their undesirable consequences. The model quantifies risks by establishing the basis of a performance-based approach to the assessment of safety standards.

Outline of the thesis

The first chapter sets out the general context and the problematic of our work. It is organized in three parts, the first part presents the general concepts of risks, in addition to a general historical overview of studies and approaches, exist for risk management. In the second part, we knew more about the hazardous materials and the different risks related to this kind of material as well as the regulations set for different modes of transport. The last part centered around the characteristics and risks of transporting petroleum products.

The second chapter, devoted to the study of the state of the art of Morocco aims to evaluate the logistics strategy adopted by Moroccan companies in terms of dangerous substances.

The third chapter presents our proposed approach for the risk assessment of the transportation of dangerous goods by road. This is a simplified approach to analyzing frequency and consequences. These analyzes should identify all relevant hazards covering the full range of potential incidents, taking into account the conditional probability of consequences arising from the occurrence of a hazardous materials accident (Gasoline and GPL). We chose the Tangier-Tétouan region as a case study to apply this approach.

In the fourth chapter, we presented a Lagrangian-based maritime and coastal risk model for petroleum products spilled from shipping according to different meteorological and sea conditions. This model to determine the areas which may be affected in the event of an oil spill has been proposed. The proposed model aims at defining the risk and the prediction of oil drift and dispersion on the surface sea. This approach has been applied in the area of the Strait of Gibraltar, which supports a significant volume of maritime traffic because it represents the navigational connection channel between the Atlantic Ocean and the Mediterranean Sea.

In the last chapter, we discuss the potential risks of facilities by describing the main likely accidents, their causes, their nature, and their consequences. This study includes a description of the analysis of the risks related to the facilities, products handled and the environment of the site. is conducted especially for a terminal of storage and distribution of hydrocarbons in the port of Tanger Med-Morocco.

Chapter I: Generality

I. Risk: Generality

I.1.Risk Definition

Risk is the measure of the instability of a dangerous or threatening situation and the potentiality of an incident, it is "*a measure of economic loss, human injury or environmental damage, both in terms of probability of incident and magnitude of loss, injury and damage*" (CCPS, 2000). It is often defined as the product between the frequency and severity of an event (Hwang et al., 2001), where the likelihood of an event occurring plays an important role in the risk assessment.

The definitions of risk can be summarized in several categories based on the concept of risk (Aven 2010, 2012; Goerlandt et al., 2015) in the following table:

Table1: The different definitions of risk

Risk definition	
risk as the expected value of the probability of an event occurrence and the utility of the consequences	Risk=Expected value (R=EV)
risk is defined risk as the probability of an undesirable event, or the chance of a loss.	Risk=Probability of an (undesirable) event (R=P)
risk is defined as objective uncertainty, i.e. a probability distribution over an outcome range (known through calculations or from statistical data analysis).	Risk=Objective uncertainty (R=OU)
represents definitions where risk is equal to uncertainty, understood as a statistical variation compared with an average value.	Risk=Uncertainty (R=U)
risk is defined as the possibility of an unfortunate occurrence	Risk=Potential/possibility of a loss (R=PO)
defines risk as the combination of the probability of occurrence of an event and consequences.	Risk=Probability and scenarios/(severity of) consequences (R=PC)
understands risk as objective states of the world, which are considered existing independent of an assessor.	Risk=Event or consequence R=C
defines risk as the combination of events, consequences and the uncertainties of these, where uncertainty is understood as an assessor’s uncertainty about the occurrence of the events/consequences	Risk=Consequences/damage/severity + uncertainty R=C+U

defines risk as an effect on stated objectives (i.e. a consequence), due to the presence of uncertainty.	Risk=Effect of uncertainty on objectives R= EUO

I.2. Risk Management

Risk management is the set of actions used to analyze, evaluate, anticipate and treat risks. It is defined as:

"Consists of a system dedicated to identifying and quantifying risks from processes or projects for appropriate decision-making to address risk" (Flanagan 1993)*;*

"Pertains to risk management planning processes: identification, analysis, reaction, steering and control" (Pritchard, 2014) *;*

"Define an architecture to manage risks in an efficient way" (AIRMIC, 2010) *;*

"A systematic approach for the identification, analysis and treatment of risks" (Mojtahedi et al., 2010).

Indeed, there are two main approaches to risk assessment: the qualitative approach and the quantitative approach (Benekos et al., 2017; Erkut, 2007).

I.2.1. Qualitative approach

The qualitative approach has been proposed for cases where numerical quantification of risk can not succeed because of the lack of information or the complexity of this task.

Qualitative risk analysis identifies hazards as well as potential accidents and qualitatively assesses consequences, frequencies and risks. The main qualitative methods dedicated to risk analysis and management are:

- ***Check list:*** Is a systemic method that verifies a system's compliance with a set of criteria that ensure its proper functioning. This method is applicable to all activities, systems, equipment and human interventions (Marhavilas, 2011);
- ***Assumptions analysis***: Based on expert brainstorming for specification of assumptions about possible deviations of a system and estimation of their potential consequences. This makes it possible to prioritize the risks and to define the appropriate countermeasures to deal with these deviations (Reniers et al., 2005; Marhavilas, 2011);
- ***Security Audit***: Is a set of applied procedures for inspection of facilities and processes (Reniers et al., 2005). This method is usually conducted by an external team to objectively verify the level of risk prevention and existing protections;

▪ ***Task Analysis:*** Is a method dedicated to the analysis of the risks engendered by human errors. Its purpose is to compare the skills of task operators with the needs of the system.

▪ ***Hierarchical task analysis***: Represents an improvement in the traditional task analysis method. The purpose of this method is to prioritize complex tasks into several sub-tasks to facilitate risk analysis (Doytchev et al., 2009);

▪ ***HAZOP***: Is a structured method whose purpose is to determine the operating deviations of a system and which are likely to generate risks. for this, HAZOP is based on individual and collective brainstorming conducted by a multidisciplinary team (NL Rosing et al., 2010; Skelton, 1997).

I.2.2. Quantitative approach

Quantitative methods consider risk as a quantity estimable by mathematical relationships by exploiting real data (Marhavilas et al., 2011). As a result, the quantification of a risk requires a capitalization of knowledge over time.

The conventional formula used for quantitative risk assessment is based on the specification of the probability of occurrence of an event and the degree of its impact:

Risk = Probability of occurrence × Consequences

Quantitative methods allow a numerical assessment of the level of risk based generally on the combination of its probability of occurrence and the degree of its impact. The main quantitative methods of risk management are:

▪ ***Quantitative Risk Assessment (QRA):*** QRA is a method for the quantification of risks that is based on the assessment of the probability and consequences of a risk event (Pasman et al., 2013);

▪ ***Proportional Risk-Assessment Technique (PRAT)*** is a risk quantification method based on the determination of the probability of occurrence, the frequency of exposure and the severity of the consequences of a risk (Marhavilas et al., 2011);

▪ ***Quantitative assessment of a domino effect scenarios*****:** is a method dedicated to the quantification of risks related to adverse events that may progress and trigger new risks (Najib 2017);

▪ ***Weighted Risk Analysis (WRA)*** makes it possible to compare several risks in one dimension. It is appropriate to balance the safety aspect with other aspects (Marhavilas et al., 2011; Suddle 2009).

There is a semi-quantitative or hybrid approach. The latter is based on the combination of both qualitative and quantitative approaches to risk treatment for rigorous evaluation. For this purpose, a qualitative method can be used to define risk evolution scenarios and to establish an initial estimate. Afterwards, a quantitative method can be applied for a precise quantification of the risks. The main method has this context:

- ***Failure tree analysis:*** This method is based on a deductive reasoning to determine the causes of the triggering of an adverse event. It makes it possible to establish logical links between the events that generate the risks. (Najib 2017);
- ***Analysis of the event tree***: This method is based on an inductive reasoning to determine the consequences generated by an initial event. Conducting this analysis leads to a qualitative description of risk evolution scenarios (Marhavilas et al., 2011). The hybridization of this method involves the specification of the probabilities of occurrence of events;
- ***Analysis of Failure Modes Effects and Consequences "AMDEC"*** which allows the analysis and prioritization of failures associated with processes and products. It is an iterative, multi-phase method that covers analysis, evaluation and processing (Nimanbeg et al., 2011) ;
- ***Hazard Analysis Critical Control Point "HACCP"*** represents a safety process for eliminating food preparation defects. To do this, it determines the critical points of the production process and integrates measures to control the quality of products at critical points (Efstratiadis et al., 2000).

In the frame of hazmat transport, risk as indicated in (Alp, 1995) is a measure of the probability and severity of harm to an exposed receptor (person , the environment) due to potential undesired events involving a hazmat. Due to this, a lot of research has been done in this context, where the risk Assessment increased interest in studying the different transportation modes such as road, rail and marine. The table 2 represents some studies related to Hazardous Materials Hazard Assessments, and table 3 provides a summary of the academic literature consisting of different aspects of the risk assessment related to hazardous materials problem in different transportation mode (Ditta et al., 2018; Erkut 2007).

Table 2: some studies related to Hazardous Materials Hazard Assessments

Risk assessment studies.	**Reference**
Present an analysis of the risks linked to the transportation of liquefied petroleum gas 'LPG' in Italy.	(Bubbico et al., 2000)
Provide an assessment tool of risks related to the transport of dangerous goods by road, rail	(Bubbico et al., 2004)
a risk analysis related to the land transport of hazardous materials in Sicily, by road, railway, and intermodal (combined rail-road) transport.	(Bubbico et al., 2006)
Studying the impact of passive protection on the reduction of the risk related to the transportation of LPG by road and rail.	(Paltrinieri et al., 2009)
Introduces the relevance of a systematic approach for the identification, quantification and mitigation of risk and presents a practical framework for risk management for the Petroleum Supply Chain.	(Fernandes et al., 2010)
develops a methodology dedicated to analyzing in a semi qualitative method and it resting on the analysis multi-criteria and on the probability to determine the risks bound to the land transportation of hazardous materials.	(Reniers et al., 2010)
a proposal to define risks relating to the transport of hazardous materials at a strategic, tactical, operational and real-time level.	(Bersani et al., 2012)
applied the HAZAN method to analyze the risks associated with the transport of hazardous materials in western India.	(Chakrabarti et al., 2012)
proposed an approach to map the risk related to hazardous materials transport by different modes in Flanders based on historical data.	(Raemdonck et al., 2013)
proposes an iterative procedure based on chaos theory on dynamic risk definition to determine the best route for transporting hazardous materials	(Mahmoudabadi et al., 2014)
proposed an approach to studying a dynamic exposure-based schedule for hazardous material transport by trains	(Bersani et al., 2016)
developed a fuzzy bilevel programming model for minimizing the total expected transportation risk when delivering products of hazardous materials to customers from multiple depots.	(Du et al., 2017)
a Quantitative Risk Analysis (QRA) methodology based on a simplified approach dedicated to hazmat road transport of gasoline by tank trucks.	(Soussi et al., 2018)

Table 3: a summary of the academic literature consisting of different aspects of the risk assessment related to hazardous materials problem in different transportation mode

Risk assessment	
Road	(Su et al.,2018; Xing et al., 2018; Soussi et al., 2018; Cordeiro et al., 2016; Sun et al., 2015; Qiu et al., 2015; Knoope et al., 2014; Xin et al., 2014; Shen et al., 2014; Kang et al., 2014; Rebelo et al., 2014; Liu et al., 2013; Tena-chollet et al., 2013; W.Y. Szeto, 2013; Roncoli et al., 2013; Chakrabarti et al., 2013; Das et al., 2012; Zhao et al., 2012; Chakrabarti et al., 2012; Hangxi et al., 2011; Chakrabarti et al., 2011; Francesca et al., 2010; Yang et al., 2010; Rashid et al., 2010; Gumus, 2009; Kheirkhah et al., 2009; Qiao et al., 2009; Trépanier et al., 2009; Francesca et al., 2009; Clark et al.,2009; Kawprasert et al., 2009; Efroymson et al., 2008; Taylor et al., 2008; M. D. Abkowitz et al., 2003; L. NARDINI et al., 2003; Jonkman et al., 2003; Fabiano et al., 2002; Hollister et al., 2002; Saccomanno et al., 2002; Verter et al., 2001; Hwang et al., 2001b; Leonelli et al., 2000; Zhang et al., 2000; Pet-armacost et al.,1999; Cassini, 1998; Mills et al.,1998; Cutter et al., 1997; Pine, 1997; Groothuis et al.,1997; Lovett, 1997; Alp et al., 1996; M. D. Abkowitz et al., 1996; Verter et al.,1996; Jayajit et al.,1996; Erkut et al., Verter, 1995; Spadoni et al., 1995; Moore et al., 1995; Macgregor et al., 1994; Gregory et al., 1994; Harwood et al., 1993; For et al., 1993; Glickman, 1991; M. Abkowitz, 1990; M. Abkowitz,1988)
Rail	(Liu et al., 2014; Rapik et al., 2014; Mahmoudabadi et al., 2014; Liu et al., 2013; Bagheri et al., 2012; Lai et al., 2011; Verma., 2011; Cheng et a.l, 2011; Kawprasert et al., 2010; Bagheri et al., 2010; Hassan et al., 2010; Vlies et al., 2008; Anderson et al., 2004; Barkan et al., 2001; Orr et al., 1998; Mcneill et al., 1991; Trust et al., 1991; Monaghan et al., 1990; SACCOMANNO et al., 1989; Swoveland, 1987; Glickman et al.,1984; Glickman, 1983)
Marine	(Wang et al., 2016; Carr et al., 2015; Siddiqui et al., 2013; Dorp et al., 2011; Brito et al., 2009; Bubbico et al., 2000; Iakovou, 2001; Roelevenatb et al., 1995; Hans et al., 1995;)
Multimodal	(Vianello et al., 2016; Strogen et al., 2016; Lu et al., 2015; Iesmantas et al., 2015; Liu et al., 2015; Vianello et al., 2014; Zhou et al., 2014; Bagheri et al., 2014; Bonvicini et al., 2014; L. Ma, Cheng et al., 2013; Jamshidi et al., 2013; Sengul et al., 2012; Nathanail et al., 2010; Vincent et al., 2010; Genserik Reniers et al., 2010; Han et al., 2010; Bubbico et al., 2009; Sosa et al., 2009; Brown et al., 2007; Samuel, 2007; Milazzo et al., 2002; ; Lafrance-linden et al., 2001; Andersson, 1994; Saccomanno et al.,1993; Purdy, 1993; Aerde et al., 1988)

II. Dangerous goods

II.1. Definition

Hazardous materials are all substances that pose a risk to the security of persons and property. The dangerous aspect of these products is due to several facts, in particular the nature of their composition or the properties of storage, transport, loading, unloading and packing (Rechkoska et al., 2012).These goods can be transported in liquid form (hydrocarbons, chlorine, propane, ...), solid (explosives, ammonium nitrate, ...) and gas (compressed coal gas…). These substances often have a higher concentration and aggressiveness than domestic ones.

According to Moroccan Law No. 30-05 concerning the transport of dangerous goods by road, proposes the following definition for a dangerous substance*:" any material, object or organism which, by its nature, may be prejudicial to persons, property or to the environment" (Gouvernment of Morocco, 2011).*

II.2. Classification of Dangerous goods

Since 1992, the United Nations has developed its own Globally Harmonized System (GHS) (Nations Unies, 2013) for the classification and labeling of chemicals according to the extent of their impact in order to standardize symbols and warnings of risks and caution between country.

The purpose of this classification is to standardize the regulations for the transport and storage of hazardous materials in relation to their classes. In addition, it specifies labels to display on packages, containers, and conveyances. These labels facilitate the recognition of classes of dangerous goods and provide basic information about the risks they may pose. This classification also determines the compatibilities between the products and the rules of segregation to be respected when storing chemicals of different classes.

Hazardous materials must be classified according to their degree of danger. This hazard(s) presented by a material must be determined on the basis of its physical and chemical characteristics and physiological properties.

In the CLP Regulation (European Chemicals Agency, 2019), new methods associated with new criteria lead to much more detailed classification of the physical hazards of substances and mixtures. These methods and criteria are inspired by those used in the field of transport.

The application of the CLP Regulation involves, in the case of physical hazards, the transition from five hazard categories into the European classification system that pre-exists sixteen hazard classes. Some hazard categories are changed and new hazard classes appear.

Hazardous materials (including mixtures and solutions) are classified into the nine classes according to their risks. Some of these classes are subdivided into divisions. These classes and divisions are as follows (Nations Unies, 2013):

- **Class 1: Explosive substances and objects**

Substances characterized by their instability, incompatibility and high reactivity, and subject to violent reactions when subjected to shock, heat or moisture.

Table 4: classification of hazardous materials for Class: explosive

Classification		**labeling**				
		Pictogram				
Danger class	**Hazard category**	**SGH**	**UN Model Regulations**	**Warning statement**	**Hazard statement**	**Hazard Mention Codes ***
Explosive material and objects			Transport prohibited	Danger	Unstable explosive	H200
	Division 1.1				Explosive, danger of mass explosion	H201
	Division 1.2				Explosive, serious danger of projection	H202
	Division 1.3				Explosive danger of fire, blast or projection	H203
	Division 1.4			warning	Fire or projection hazard	H204
	Division 1.5	no pictogram		Danger	Danger of mass explosion in case of fire	H205
	Division 1.6	no pictogram		No warning mentions	No danger statements	-

■ Class 2: Gases

This class covers pure gases, gas mixtures, mixtures of one or more gases with one or more other substances and articles containing such materials. We hear a matter that:

- At 50 ° C at a vapor pressure above 300 kPa (3 bar); or
- Is completely gaseous at 20 ° C at the standard pressure of 101.3 kPa.

a-Flammable gases (including chemically unstable gases)

Includes all products that can catch fire when exposed to heat, spark, or flame.

Table 5: classification of hazardous materials for Class: Flammable gases

Classification		labeling				Hazard Mention Codes
Danger class	Hazard category	Pictogram: SGH	Pictogram: UN Model Regulations	Warning statement	Hazard statement	
Flammable gases	1			Hazard	Extremely flammable gas	H220
	2	No pictogram	Not prescribed	warning	Flammable gas	H221
	A (chemically unstable gas)	No additional pictogram	Not prescribed	No additional warning	Additional danger statement Can explode even in the absence of air	H230
	B (chemically unstable gas)	No additional pictogram	Not prescribed	No additional warning	Additional danger statement May explode even in the absence of air at high pressure and / or temperature	H231

**Hazard statements the hazard statements describe the nature of the hazard, or even the degree of hazard. A unique alphanumeric code is assigned to each hazard statement. It consists of: the letter "H" (for "Hazard statement"; three digits the first digit indicates the type of hazard: "2" for physical hazards; "3" for health hazards; "4" for environmental hazards the next two digits correspond to a sequential hazard numbering. For example, codes 200 to 210 are reserved for the danger of explosions*

b- Non-flammable, non-toxic gases.

Table 6: classification of hazardous materials for Class: Non-flammable (class 2)

Classification		labeling				Hazard Mention Codes
Danger class	Hazard category	Pictogram: SGH	Pictogram: UN Model Regulations	Warning statement	Hazard statement	
Flammable gases	1			Hazard	-Extremely flammable gas -Container under pressure: may burst under the effect of heat	H222 H229
	2			warning	-Gas flammable	H223 H229

					-Container under pressure: may burst under the effect of heat	
	3	no pictogram		warning	-Container under pressure: may burst under the effect of heat	H229

c- Oxidizing gases

Any substance that may cause or promote the combustion of another material by releasing oxygen or other oxidizing material or that contains an organic substance having the following bivalent oxygen structure: "-0-0-"(Peroxydes).

Table 7: classification of hazardous materials for Class: oxidizing gases (class 2)

Classification		**labeling**				**Hazard Mention Codes**
		Pictogram		**Warning statement**	**Hazard statement**	
Danger Class	**Hazard category**	**SGH**	**UN Model Regulations**			
Oxidizing Gases	1			Danger	May cause or aggravate a fire; oxidizer	H270

d- Gas under pressure

Includes any product, material or substance that is under pressure and may explode when the container is subjected to heat or shock.

8: classification of hazardous materials for Class: Gas under pressure (class 2)

Classification		**labeling**				**Hazard Mention Codes**
		Pictogram		**Warning statement**	**Hazard statement**	
Danger class	**Hazard category**	**SGH**	**UN Model Regulations**			
Gas under pressure	Compressed gas			warning	Contains gas under pressure; may explode under the effect of heat	H280
	Liquefied gas			warning	Contains gas under pressure; may explode under the effect of heat	H280
	Refrigerated Liquid gas			warning	Contains refrigerated gas; may cause cryogenic burns or injury	H281
	Dissolved gas			warning	Contains gas under pressure; may explode under the effect of heat	H280

■ Class 3: Flammable liquids

Flammable liquids: are liquids, liquid mixtures, or liquids containing solids in solution or suspension that emit flammable vapors at a temperature not exceeding 60 ° C in a crucible or 65.6 ° C in an open crucible; this temperature is commonly called a flash point. Class 3 includes the following subjects:

- Flammable liquids
- Liquid desensitized explosive substances.

Table 9: classification of hazardous materials for Class: flammable liquids

Classification		labeling				Hazard Statement codes
		Pictogram		Warning notice	Hazard statement	
Danger Class	Hazard category	SGH	UN Model Regulations			
Flammable liquids	1			Danger	Extremely flammable liquid and vapor	H224
	2			Danger	Highly flammable liquid and vapor	H225
	3			warning	Flammable liquid and vapor	H226
	4	No pictogram	Not prescribed	warning	Combustible liquid	H227

■ Class 4: Flammable solids

Class 4 consists of the following three divisions:

(***a). Flammable solids***: are substances which, under the conditions encountered during transport, ignite easily or which may cause or aggravate a fire by friction; self-reactive materials likely to undergo a strongly exothermic reaction; desensitized explosive substances which may explode if not sufficiently diluted;

(***b). Substances subject to spontaneous ignition:*** are substances liable to spontaneously heat up under normal conditions of transport, or to heat up in contact with the air, and which may then ignite;

(c). Substances which, in contact with water, emit flammable gases: Substances which, by reaction with water, are liable to ignite spontaneously or to release flammable gases in dangerous quantities.

Table 10: classification of hazardous materials for Class: flammable solids (a)

Classification		labeling				
		Pictogram				
Danger class	**Hazard category**	**SGH**	**UN Model Regulations**	**Warning notice**	**Hazard statement**	**Hazard Statement codes**
Flammable liquids	1			Danger	Flammable solid	H228
	2			Danger	Flammable solid	H228

Table 11: classification of hazardous materials for Class: flammable solids (b)

Classification		labeling				
		Pictogram				
Danger class	**Hazard category**	**SGH**	**UN Model Regulations**	**Warning notice**	**Hazard statement**	**Hazard Statement codes**
Self-reactive substances	Type A		May not be accepted for carriage	Danger	May expose under the effect of heat	H240
	Type B	 	 	Danger	May ignite or explode under the effect of heat	H241
	Type C & D			Danger	May ignite under the effect of heat	H42
	Type E & F			warning	May ignite under the effect of heat	H242
	Type G	no pictogram	Not prescribed	No warning mention	No hazard statement	none

Table 12: classification of hazardous materials for Class: flammable solids (c)

Classification		labeling				Hazard Statement codes
		Pictogram				
Danger class	**Hazard category**	**SGH**	**UN Model Regulations**	**Warning notice**	**Danger statement**	
Substances which, in contact with water, emit flammable gases	1			Hazard	In contact with water releases flammable gases which may ignite spontaneously	H260
	2			Danger	In contact with water releases flammable gases	H261
	3			warning	In contact with water releases flammable gases	H261

- **Class 5: Oxidizing substances and organic peroxides**

Class 5 includes the following two divisions:

(a). Oxidizing substances: which, although not necessarily combustible themselves, can, in general by giving up oxygen, cause or encourage the combustion of other materials. These materials can be contained in objects;

(b). Organic peroxides: are the organic materials containing the bivalent structure -O-O- and can be considered as derivatives of hydrogen peroxide, in which one or two hydrogen atoms are replaced by organic radicals. Organic peroxides are thermally unstable materials, which can undergo an exothermic self-accelerating.

Table 13: classification of hazardous materials for Class: oxidizing substance and organic peroxides(a)

Classification		labeling				Hazard Statement codes
		Pictogram				
Danger class	**Hazard category**	**SGH**	**UN Model Regulations**	**Warning notice**	**Hazard statement**	
Oxidizing substances	1			Danger	May cause fire or explosion; powerful oxidize	H271
	2			Danger	May cause a fire; oxidizer	H272
	3			Danger	May aggravate a fire; oxidizer	H272

Table 14: classification of hazardous materials for Class: oxidizing substance and organic peroxides(b)

Classification		**Labeling**				**hazard statement codes**
Danger class	**Hazard category**	**Pictogram** **SGH**	**UN Model Regulations**	**Warning notice**	**Danger statement**	
Organic peroxides	Type A		May not be accepted for carriage	Hazard	May expose under the effect of heat	H240
	Type B	 	 	Danger	May ignite or explode under the effect of heat	H241
	Type C & D			Hazard	May ignite under the effect of heat	H42
	Type E & F			Warning	May ignite under the effect of heat	H242
	Type G	No pictogram	Not prescribed	No note of warning	No hazard statements	none

- **Class 6: Toxic and infectious substances**

Any substance that in one exposure can lead to death. Class 6 includes the following two divisions:

(a). Toxic substances: are substances that can cause death or serious disorders, or be harmful to human health if they are absorbed by ingestion, inhalation or dermal;

(b). Infectious Substances: These are materials known or suspected to contain pathogens. Pathogens are defined as microorganisms (including bacteria, viruses, rickettsia, parasites and fungi) and other agents such as prions, which can cause diseases in humans or animals.

Table 15: classification of hazardous materials for Class: Toxic and infectious substances

Classification			labeling				Code of The hazard statements
Danger class	category of danger		Pictogram		Warning statement	Hazard statement	
			SGH	ONU model Regulations			
Organic peroxides	1	Oral			Danger	Deadly if swallowed	H300
		Cutaneous				Deadly in contact With skin	H310
		Inhalation				Inhalational death	H330
	2	Oral			Danger	Deadly if swallowed	H300
		Cutaneous				Deadly in contact With skin	H310
		Inhalation				Inhalational death	H330
	3	Oral			Danger	Deadly if swallowed	H301
		Cutaneous				Deadly in contact With skin	H311
		Inhalation				Inhalational death	H331
	4	Oral		Not Prescribed	Warning	Harmful if swallowed	H302
		Cutaneous				Deadly in contact with skin	H312
		Inhalation				Harmful by ingestion	H332
	5	Oral	No pictogram	Not Prescribed	Warning	May be harmful if swallowed	H303
		Cutaneous				May be harmful by skin contact	H313
		Inhalation				May be harmful if inhaled	H333

- **Class 7: Radioactive material**

Radioactive material means any material containing radionuclides for which both the mass activity and the total activity in the consignment exceed the basic values for radionuclides.

- **Class 8: Corrosive substances**

Corrosive substances are those materials which, by chemical action, can cause serious damage to living tissue and which, in case of leakage, may damage or even destroy other goods or transport equipment.

Table 16: classification of hazardous materials for Class: Corrosive substances

Classification		**Labeling**				**Hazard mention codes**
		Pictogram				
Danger class	**Hazard category**	**SGH**	**UN model Regulations**	**Mention warning**	**Hazard statement**	
Corrosive materiel	1			warning	Causes severe skin burns and serious eye damage	H314
	2		Not prescribed	warning	Causes skin irritation	H315
	3	No pictogram	Not prescribed	warning	Causes mild skin irritation	H316

- **Class 9: Miscellaneous Hazardous Materials and Objects**

The substances and articles of Class 9 are substances and articles which, during transport, present a danger other than that referred to in other classes.

II.3. Regulation of the Transport of Dangerous Goods (TDG)

The transport of dangerous goods is governed by strict international regulations - (issued from UN recommendations) - and specific to each mode of transport:

- **<u>Transport by land</u>**: ADR (European Agreement Concerning the International Carriage of Dangerous Goods by Road), RID (Regulation concerning the International Carriage of Dangerous Goods by Rail), (rail) and ADN (European Agreement on International Transport) dangerous goods by inland waterway (fluvial);
- **<u>Maritime transport:</u>** IMDG (International Maritime Dangerous Goods);
- ***<u>Air transport:</u>*** is governed by the IATA rules (International Air Transport Association,).

a) Road transport

Road TDG is governed by the ADR (European Agreement on the International Carriage of Dangerous Goods by Road) (Nations Unies, 2019), (which was adapted in Moroccan law by the Decree of 29 May 2009 (TDG Order) (Gouvernment of Morocco, 2011)).

This European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) was obtained in Geneva on 30 September 1957 under the auspices of the United Nations Economic Commission for Europe, which came into force on 29 January 1968.

The agreement covers all land transport of dangerous goods, as well as all loading or unloading of these materials. The agreement contains technical rules relating to :

- the definition of materials by classes, according to their risks (explosives, compressed or liquefied gases, flammable, toxic, radioactive, corrosive, etc.);
- packaging (technical provisions, tests, approval procedure for packaging and distinctive marking);
- tanks (construction, approval of prototypes and tests of resistance and sealing);
- vehicles (electrical circuits, fire extinguishers, braking, speed limitation by construction, first intervention equipment, certificate of approval);
- labeling and signage, so that emergency and response services are immediately informed of the presence of hazardous materials. Vehicles must have rectangular orange panels. For tanks, this sign contains the hazard code (2 for compressed or liquefied gases, 3 for flammable, 6 for toxic, etc.), as well as the material number.

There are also danger labels bearing a danger symbol (flame for flammable, human skull for toxic, helix for radioactive ...).

The parking and unloading rules are also specified as well as the different risks (and their consequences) listed in the ADR order.

b) Rail transport:

Rail TDG is covered by RID, the regulation concerning the international carriage of dangerous goods by rail (OTIF, 2019).

In order to guarantee everyone's safety and preserve the environment, RID establishes the list of so-called dangerous goods; those that are excessively dangerous can not travel by rail.

The others can, provided that several rules are respected, loading until final delivery. Each of the 13 classes of dangerous goods is subject to specific provisions.

The obligations incumbent on the shipper and the carrier of dangerous goods are listed in RID. They concern in particular (OTIF, 2019):

- the safety measures to be taken when loading and unloading the dangerous goods ;
- all the checks to be done before the wagon is sent ;
- transport information : the driver must be aware of the contents of the load and its dangerousness, wagons must be placarded, etc..;
- parking conditions and transportation ;
- the measures to be taken in case of incident or accident.

c) Maritime transport:

The transport of dangerous goods by sea is governed by the International Maritime Dangerous Goods Code (IMDG Code) (IMO, 2018). Very precise packaging and documentation standards must be followed. Each shipment is inspected prior to boarding and may be subject to rejection resulting in delays and loss of trade.

Products normally exempt from land transport regulations are regulated for maritime transport (ex: aerosols, perfumes, combustible liquids, etc.). In addition, specific standards of segregation are implemented.

II.4. Risks related to hazardous materials

Dangerous Goods (TD) are transported in different ways around the world. The risk of TDG refers to the consequences of an accident occurring during the transportation of these goods by road, rail, waterway or pipeline. The main categories of risks related to the transport of dangerous goods (ELAbde, 2015):

- **the explosion hazard,** which is a result of rapid combustion generating a large amount of gas at such a high temperature, pressure and expansion speed as to cause damage to the surroundings;
- **the risk of fire**, which corresponds to a reaction resulting from the presence of several factors (heat source, oxidizer, fuel) and which causes a significant release of heat, resulting in burns or injuries that are often very serious;
- **the toxic risk**, which can cause poisoning or even death, by inhalation, contact or ingestion of a toxic chemical substance following a leak of toxic products. The dispersion of the hazardous material can be done in air, water and / or soil. In the aerial case, the toxic cloud will move away from the accident site in response to active winds;
- **the risk of radioactivity** in the case of materials emitting dangerous radiations that can reach all living beings;
- **infectious risk**, which can cause serious diseases in living beings. This risk is specific to materials containing infectious micro-organisms such as viruses, bacteria, ...

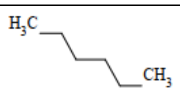
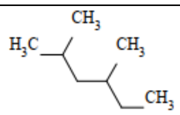
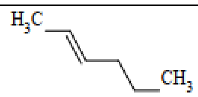
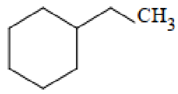
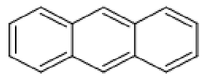
At the environmental level, the environmental impacts are generally much more complex to measure and quantify because it can take several years before their effects appear and may have as their target the fauna, the flora, the soil and / or water (Peignier, 2010),for example, in Seveso, Italy, on July 10, 1976, a cloud containing dioxin escaped from a plant causing heavy damage to the surrounding flora and fauna (70,000 killed heads, defoliated trees) (Henkel, 2018).

III. Hydrocarbons

Hydrocarbons are complex mixtures of chemical compounds, their molecules contain only carbon and hydrogen; they are grouped into several chemical families according to their structure based on the quadrivalence of carbon as shown in the table 17 (Wauquier, 1994) :

- ***Saturated hydrocarbons (Alkanes):*** are the family of molecules composed only of carbon and hydrogen. Normal paraffins called N-paraffins (linear alkanes) or iso-paraffins (branched alkanes) are distinguished;
- ***Unsaturated hydrocarbons***: which has at least two carbon atoms connected by a multiple bond (double or triple). There are: alkenes (olefins) (C_nH_{2n}) and alkynes (C_nH_{2n-2});
- ***Naphthenes:*** they consist of at least one benzene ring with 6 carbon atoms. The smallest and most volatile compounds are benzenes, toluene, ethylbenzene and xylene;
- ***Aromatic hydrocarbons***: they are, as their name indicates, constituted of at least 2 benzene cycles and constitute between 0% and 60% of the hydrocarbon composition.

Table 17: Structure of hydrocarbon compounds present in petroleum products
Source : (Laxalde, 2012)

Families	N-Paraffins	Iso-Paraffins	Alkene	Naphtalene	Aromatic
Formulas	C_nH_{2n+2}	C_nH_{2n+2}	C_nH_{2n}	C_nH_{2n}	C_nH_{2n-8k}
Examples					

n : number of carbon atoms, k : number of unsaturation

III.1. Characteristics of hydrocarbons

- ***The flash point:*** This is the temperature at which a product releases enough vapor to form a flammable mixture with air in contact with a flame or spark. Flash points for petroleum products are highly variable, they can easily ignite as long as the volatile compounds have not evaporated and are dispersed in the atmosphere (Fingas, 2013). The flash point is expressed in degrees Celsius, Table 18 represent flash point values of petroleum products;

Table 18: Specificities of liquid fuels (Source: Total)

Combustibles	**Flash point (°C)**	**LEL (%)***	**UEL (%)***
Gasoline	-35	1	7
petroleum	35 à 60	0.7	5
Diesel	> 55	6	13.5
Acetone	18	2.6	13
Benzene	11	1.4	7
Kerosene	37	0.7	5
Toluene	4	1.4	6.7
Crude	-10	1	18

** LEL (Lower Explosive Limit) and LES (Upper Explosive Limit)*

■ ***The density*** of hydrocarbons corresponds to the mass per unit volume. This property is used to distinguish light and heavy hydrocarbons. It is also important for indicating the buoyancy of hydrocarbons in the water in the event of a spill (CEAEQ, 2015). In fact, hydrocarbons almost always have a density of less than $1g/cm^3$, which allows them to float. However, once spilled, aging phenomena (evaporation and especially emulsification) gradually increase their density to values close to those of brackish or fresh water, which makes their buoyancy more uncertain (Cedric, 2012);

■ ***Viscosity*** can be defined as the resistance to the flow of a liquid. As a result, in the event of a spill accident, it influences the spread of a layer of hydrocarbons on the surface of the water. Petroleum hydrocarbons with low viscosity are very fluid and spread rapidly, making their containment difficult. It is important to note that viscosity is influenced by temperature. Indeed, the lower the temperature, the higher the viscosity (CEAEQ, 2015);

■ ***Pour point:*** is defined by the temperature at which the product begins to flow. In the case of hydrocarbons, when the ambient temperature is below this point, the hydrocarbon behaves like a solid (Cedric, 2012);

■ ***Solubility:*** The ability of a substance to dissolve in the water column. This property is important in hydrocarbons because some, once solubilized, can be toxic to aquatic organisms, even at very low concentrations (Fingas, 2013);

The most soluble petroleum hydrocarbons are essentially light aromatics such as benzene. Moreover, the greater the proportion of light hydrocarbons, the greater the solubility of the petroleum product in water (CEAEQ, 2015). The table below represents the properties of some petroleum products (Fingas, 2013).

Table 19: Properties of the main petroleum hydrocarbons

Property	**Gasoline**	**Diesel**	**Crude oil**	
			Lightweight	*Heavy*
Flash point (°C)	-35	>55	-30 to 30	-30 to 60
Density g/ml (15°C)	0.72	0.84	0.78 to 0.88	0.88 to 1.00
*API Density (API degree) **	65	35	30 to 50	10 to 30
Viscosity (mPa.s (15°c))	0.5	2.0	5 to 50	50 to 50,000
Pour point (°C)	-	-35 à -10	-40 to 30	-40 to 30
Solubility mg/l	200	40	10 to 50	5 to 30

**The density scale of the American Petroleum Institute (API) is commonly used to describe the density of petroleum hydrocarbons, which is then expressed in API degree (API: it's a measure of the heaviness or liquidity of a petroleum liquid is compared to water).*

III.2. Risks related to the transport of hydrocarbons

The risk of transporting hazardous materials, specific to hydrocarbons, is the result of an accident occurring during the transport of these substances by road, rail, sea or pipeline. There are three types of effects that can be associated:

■ **Explosion:** may be caused by a shock with spark production (especially for flammable gas tanks), by heating a tank of volatile or compressed product, by the mixing of several products or by the unexpected ignition of artifices or ammunition. The explosion can have both thermal and mechanical effects (effect of overpressure due to the shock wave). These effects are felt near the disaster and up to a radius of several hundred meters;

The main consequences of the explosion can be:

- Flammable vapor cloud which is within the flammable limits of the fluid;
- Explosions can be confined or unconfined;
- Confined explosions are far more hazardous;
- Degree of confinement increases flame speed;
- Air burst or ground burst depending on cloud buoyancy.

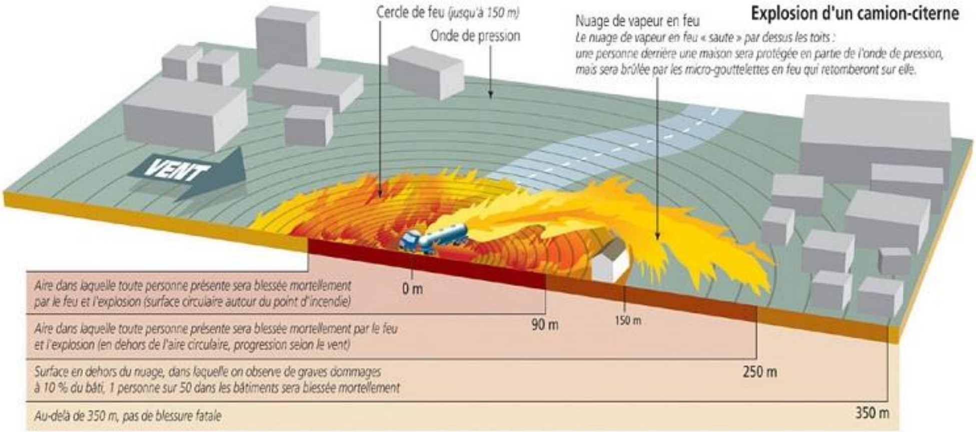


Figure 1: The possible consequences of an explosion accident of a tanker truck (source: Ministry of Ecological and Solidarity Transition- France)

■ **A fire** can be caused by the abnormal heating of a vehicle organ, an impact against an obstacle (with sparks), the accidental ignition of a leak, an explosion in the immediate vicinity of the vehicle, even a sabotage Indeed, 60% of TDG accidents involve flammable liquids. A fire of solid, liquid or gaseous flammable products generates thermal effects (burns), which can be aggravated by problems of asphyxiation and intoxication, related to the emission of toxic fumes (Ministry of Ecological and Solidarity Transition- France, 2019);

The main consequences of the flammable can be:

➢ ***Pool Fire***

- Flammable liquid spilled on land / water;
- Storage tank roof fire ;
- Confined area (tank size, or containment bund), or unconfined;
- Heavier hydrocarbons burns with smoky flame, light hydrocarbons burns with much brighter flame.

Figure 2: Pool fire consequence of an accident of HM
(source: Pierre Palmberg)

- ***BLEVE (Boiling Liquid Expanding Vapor Explosion) :***

- Failure of pressure vessel containing pressurised liquid;
- Pressure drop causes violent boiling, rapid expansion and vaporisation ;
- Typically occurs due to external heat source from other process emergency (e.g. jet fire) impinging on vessel;
- Flammable liquids lead to fireball;
- Flame spreads through 360° ;
- Can occur with non-flammable liquids, e.g. steam explosion.

Figure 3: BLEVE consequence of an accident of HM
(source: Pierre Palmberg)

➢ ***Jet Fire***

- Pressurised release of flammable liquid or vapor;
- Intentional (flare);
- Accidental (leak, relief valve);
- Jet is pointed in one direction;
- Can be affected by wind.

Figure 4:Jet fire consequence of an accident of HM (source: Pierre Palmberg)

■ **A toxic cloud release** can be from a leak of toxic or result from combustion (even a non-toxic). When spread through the air, water and / or soil, hazardous materials can be toxic by inhalation, direct or indirect ingestion, consumption of contaminated products, contact. Depending on the concentration of the products and the duration of exposure, the symptoms range from simple irritation of the skin or a tingling sensation of the throat, to serious attacks (asphyxia, pulmonary edema). These effects can be felt up to a few kilometers from the site of the disaster.

The main consequences of the toxic scenario can be:

The different methods to categorise toxic effect: (Toxicity varies from chemical to chemical)

- Emergency Response Planning Guidelines (ERPG) (60 minutes)
- ❖ ERPG 1 – Mild effects, objectionable odor
- ❖ ERPG 2 – Serious health effects
- ❖ ERPG 3 – Life threatening health effects
- Immediately Dangerous to Life and Health (IDLH) (30 minutes)
- Short Term Exposure Limit (STEL) (15 minutes)

Figure 5: toxic consequence of an accident of release of toxic chemicals
(Source: U.S. Chemical Safety Board)

Chapter II: State of art

Case study: Morocco

Partially reproduced from: Soussi et al., "Storing and transporting hazardous material, logistics strategies for Moroccan companies". Advances in Science, Technology and Engineering Systems Journal, 5(1): 21-33 (2020) DOI: 10.25046/aj050104

Introduction

The number of industrial companies producing, using, storing and, or transporting Hazardous Materials (HM) is constantly increasing worldwide due to the growth of demand in various sectors (Yang et al., 2010). Because of their nature, these materials require special attention. Hazardous Material accidents are rare events Yet their occurrence can result in catastrophic industrial consequences. Here we can take the example of chemical accidents that are defined as the release of notable amount of toxic materials during storage, production, transportation, use and disposal of chemicals. Such accidents may lead to a real disaster. For instance poisoning which affects in a serious way all the people the properties and the environment (Kara, 2004; Zhang et al., 2000; Verter et al., 1996).

In general, risk is well defined in terms of both the likelihood of the incident and the magnitude of the loss, injury, and damage as a measure of economic loss, human injury, or environmental damage (Soussi et al., 2018; CCPS, 2000). To define a risk able to manage aid decision makers in the transport of dangerous goods, it is useful to refer to a classification hierarchy of the decisional levels that may be associated with the management of that type of transport taking into account economic, environmental, and risk aspects (Bersani et al., 2012; Bersani et al., 2010).

The risk of transporting Hazardous Materials varies depending on the type of substance. Transporters of hazardous goods must be aware of how these materials are classified to ensure compliance with marking, labeling, placarding, and shipping paper requirements (Rechkoska et al., 2012). Hazardous materials may be classified in any of the following: explosives, gases, flammable liquids, flammable solids, oxidizing substances, poisons and infectious substances, radioactive material, corrosives, miscellaneous goods, and other regulated materials (Rechkoska et al., 2012).

Hazardous Materials transport incidents may occur at the origin or at the destination (loading and unloading) or on the route (Erkut, 2007). Studies have shown that the frequency of accidents during the transport of dangerous goods by road and rail has increased (Oggero et al., 2006). Most of these accidents were followed by fire, explosions and gas clouds (Conca et al., 2016; Darbra et al., 2010). As an example, Statistically, there were 11,000 hazmat transport companies involving 310,000 vehicles and 1.2 million employees in China in 2015 (Huang et al., 2018).

In recent decades, several historical surveys have been published on accidents in chemical plants and in the transportation of hazardous materials (Fabiano et al., 2012; Planas et al., 1997; Vilchez et al., 1995; List et al., 1991). A survey of accidents that occurred during HM's road and rail transport shows that accidents frequency has increased in the 20th century, most of which are on the road (Oggero et al. 2006). Another survey was conducted on the practices of firms hazmat handling facilities, this research focused on hazmat shipments and mode of transportation and various HM and outsourced activities (Leroux et al., 2010). In (Peignier et al., 2011) the authors conducted a survey covering both technical elements of HM such as the class of these materials, geographic sites covering activities, supply and shipping, various practices related to HM (loading / unloading) and organizational elements for companies using hazardous materials (risk management, emergency preparedness, training, subcontractors). A survey of the accident situation of tankers carrying hazardous materials was conducted in order to identify the different causes and hazard classes for HM accidents, consequences and corresponding probabilities (Shen et al., 2014).

The study of the literature shows that a multitude of models have developed to take into account different risks on different parts of the supply chain, to various activities (Ditta et al., 2018; Verma, 2011; Raemdonck et al., 2013; Erkut et al., 2005). Thus, decisions at the operational level (for example, a truck driver) will not be the same as those taken at the tactical level (for example, the head of the part of the company), nor even as those taken at the strategic level (for example, the management team). Yet, each can opt for the best decisions according to their own point of view, their own information and their own objectives. The purpose is to assure a vertical cooperation in order not to have these various objectives in confrontation with one another on the decision-making plan. For instance, a decision taken at the operational level which improves the performance of the activities of the truck driver, could really have negative impacts on the global performance of the chain (channel).

Nowadays in Morocco the chemical materials are used in the most productive sectors including industry, agriculture, health, mining and quarrying and consumption (IMIST, 2012). However, the chemical industry is based, essentially, on three classes of products in this case: petroleum products, industrial chemicals and fertilizers.

The dangerous consequences of HM accidents have urged the Moroccan legislation to pay serious attention to the transportation of this type of materials. HM are defined in the Moroccan law N°30-05 as any material, object or organism which, by reason of its nature, may harm the people, the properties and the environment. No research to our knowledge in this area has been conducted in Morocco to assess the overall situation.

The purpose of this study is providing a current survey on the situation of Hazardous Materials in Moroccan companies in order to identify locations, types and classes of HM, logistics chain (supply and shipping), risk management, training of the companies with regard to these materials.

Within this background, the present study aspires to (1) know the companies' methods of supplying and shipping HM (mode, frequency, and type of transport used) and the reasons behind such choices, (2) know the distribution of tasks between the shipper and the carrier during the loading and unloading operations of HM, (3) determine the different storage locations, (4) determine the HM related items representing the largest costs to companies (5) test the ability and willingness of companies to invest in risk reduction measures, (6) know the sector where subcontractors are used for operations related to HM, (7) check the companies' interest / involvement in the activities of their subcontractors, (8) find out the different risk reduction measures, (9) determine the impacts of HM accident, and finally (10) verify whether the current legislation holds industrial activities related to HM or not.

I. State of the art: Hazardous Materials Survey

I.1. Survey by questionnaire

The survey's objective is to assess the companies' fixed sites and refer to logistic strategies that are adopted by them in terms of Hazardous Materials (HM). Since the two relevant factors (cost and risk) can affect such strategies, it is essential to understand the role played by these factors within these strategies. To sum up, these have been considered the hearth of the supply chain and have been assessed based on: (a) their procurement practices, (b) their expedition practices, (c) their practices on the site of their company. It is noted that the completion of this questionnaire was based on a study in Canada on the logistics choices of hazardous materials (Nathalie et al., 2013)

This questionnaire was sent to 103 companies that are concerned with HM from different sectors. In a period of 14 months we have received the responses of 55 companies (53.40%) as indicated in the following table which also provides the companies' field of activity.

Table 20: Companies that responded to the questionnaire and their field of activity

Companies activity	**Numbers**
Health and pharmaceutical	3
Automotive industry	8
Chemistry and oil	8
Energy & Research	7
other industrial activities	12
Aviation industry	4
building and public works & Construction	5
Food Industry	5
Transport and logistics	3
Total	55

The questionnaire consists of various sections; each section focuses on a particular aspect of the company activities. These sections are detailed as follow:

a. Company Identification

This domain of the survey helps gather general information about the company in order to obtain a quick overview (company's name, number of employees, activity area…). And it also used to collect information related to the contact person and allows the transfer of results to the participating company.

b. Identification of a site where there is HM

This part of the survey asks the respondent to identify, among all the installations belonging to the company, a site where there are HM. All the following questions are specific and will be about this site. This choice was made for the sake of consistency in the responses, the nature and intensity of practices that can vary greatly from one site to another. Once the site is identified, the following information are gathered:

- The number of employees on the site;
- The geographical coverage of the site activities;
- The shared part of activities related to Hazardous Materials;
- The transport of Hazardous Materials classes found on the site;
- The name of three main Hazardous Material found in the site.

c. Supply of Hazardous Materials

This part of the questionnaire focuses on practices related to the supply of Hazardous Materials. Supply issues have been separated from shipping issues because these practices may vary depending on these two functions of the company. Some companies supply HM but they ship very little, usually in the form of residual hazardous materials. Questions related to supply issues focus on :

- The number of Hazardous Materials received on the site;
- The frequency of the receptions;
- The mode of transport used for the supplies;
- The packing used;
- The conditions surrounding unloading;
- The use of subcontracting.

d. Shipment of Hazardous Materials

This part of the questionnaire focuses on practices surrounding shipments of Hazardous Materials. It is considered as a mirror of the previous section on supplies (c), the same questions are asked.

e. Hazardous Material at identified fixed site

This part is mainly interested in the different places of storage on the identified fixed site. More precisely, the questions can be used to determine whether the company uses temporary storage sites inside or outside its site. In addition, the questions check whether companies have hazardous material transported frequently in order to reduce the quantities on the site.

f. HM Supply related costs

This part focuses on costs related to Hazardous Materials. The questions are about :

- The criteria used by the company during these choices of supply, which makes it possible to weight the importance of the cost factor;
- The importance given by the company to various factors related to Hazardous Materials (specialized vehicles, equipping, training, etc...);
- The maximum percentage increase in operating costs that the company could tolerate to invest in security measures;
- The weighting of the economic impact of different types of accidents on the company.

g. Subcontractors with activities related to Hazardous Materials

This part of the questionnaire is interested in the use of subcontracting, a common measure to most companies. The objective is in particular to verify if this practice can have repercussions on the security level. The questions asked are relate to:

- The sectors (transport, unloading, on-site handling, packaging, etc.) and where the company uses subcontractors for its Hazardous Materials activities;
- The reason which drives companies to use subcontractors;
- The level of knowledge that companies have about the activities of their subcontractors;
- The type of contracts linking companies to their subcontractors;
- The possible loss of accountability that the business suffers when using subcontractors;
- Measures to monitor the activities of subcontractors;
- The important criteria when selecting a subcontractor.

h. Risk control

This part of the questionnaire focuses on the risk management measures put in place by the companies. The questions concern:

- The risk management measures put in place on the site and during transport;
- The risk communication policy put in place by the company;
- Procedures surrounding accidents / incident management;
- The possible impacts (immediate direct cost, loss of production, image loss, etc.) of a Hazardous Material accident on the company;
- The relative importance of different types of accidents (fixed site vs. transportation).

i. Regulation Hazardous Materials

This part of the questionnaire is interested in the manner in which the companies are cooperating in accordance with the regulations on dangerous materials. Among other things, the questions check whether the different regulations (storage, transport) constrain the company's activities and whether, according to them, these regulations make it possible to manage the risk effectively.

II. Results and Discussion

At this juncture; we shall present the rough results and their analysis. The first part of the chapter is dedicated to the presentation of the results obtained from the fixed sites. The second part analyzes these results and the third part introduces the differences noticed between the small and the large companies that used hazardous materials.

II.1. Answers obtained

A total of 103 questionnaires have been supplemented to date. Four of these answers come from an intermediate version from the questionnaire which explains the high number of abstentions to the questions related to the different Residual Hazardous Materials (HMR) received or shipped on the site, frequency training offered, the maximum percentage increase in current operating costs, the economic impact on the business of an HM accident involving employees and public, personnel or departments dedicated to risk management, information or communication on the management of risks to employees, and the organization and planning of on-site activities with clients, suppliers and subcontractors.

The answers to the questions related to the Company Name and the Name of the “contact person” and to the first part of the identification of a site where there are Hazardous Materials (HM) are not presented, in order to preserve the identity of the guarantors. Moreover, the answers were compiled and are presented in a grouped way to obtain accurate statistics and to prevent the identifies of the companies from being exposed based on the answers.

The answers obtained come from various horizons: branches of the industry, cuts of the company and portions of the activities related to the HMs

II.2. Analysis of the results

The following parts aim at analysing the answers obtained in the survey in order to establish bonds between the various elements and to draw essential conclusions. In this section, no distinction is made between the various classes of companies.

II.2.1. Characteristics of the responders

In this part, we shall deal with the first two sections of our survey. Namely; the identification of companies and the site where Hazardous Materials are present.

The companies which have answered the questionnaire belong to different sectors, as indicated in table 21 which also provides the companies sector of activities. Most of them belong to the groups of large companies (40% have between 250 and 5000 employees), averages (38.2% have between 50 and 249 employees), while a moderate percentage contains small companies (10.9% have between 10 and 49 employees) as shown in Table 22.

Table 21:Sector of Activities of the companies participating in the survey

Activity sector	Numbers	Percentage	Valid Percentage	Cumulative percentage
Health and pharmaceutical	3	5.5	5.5	5.5
Automotive industry	8	14.5	14.5	20.0
Chemistry and oil	8	14.5	14.5	34.5
Energy & Research	7	12.7	12.7	47.3
Other industrial activities	12	21.8	21.8	69.1
Aviation industry	4	7.3	7.3	76.4
Building and public works & Construction	5	9.1	9.1	85.5
Food Industry	5	9.1	9.1	94.5
Transport and logistics	3	5.5	5.5	100.0
Total	55	100.0	100.0	

Table 22: Number of employees in the companies participating in the survey

Number of employees	Numbers	Percentage	Valid Percentage	Cumulative percentage
Between 250 and 5000	22	40.0	40.0	40.0
Between 10 and 49	6	10.9	10.9	50.9
Between 50 and 249	21	38.2	38.2	89.1
< 10	1	1.8	1.8	90.9
> 5000	5	9.1	9.1	100.0
Total	55	100.0	100.0	

More than half of the guarantors (78.2%) use more than one site to carry out their activities related to hazardous materials, these sites are divided into two types, factory or warehouse. It should be pointed out that most of the participants, (69.1%) are using the factory for these activities (30.9% using warehouse) (figure 6). These sites have more than one geographic coverage whether it is local, regional or national as shown in table 23.

Table 23 Geographic coverage of supplies and shipments of the site:

Geographic coverage of supplies and shipments of the site	Answer	Numbers	Percentage	Valid Percentage	Cumulative percentage
Local	Yes	9	16.4	16.4	16.4
	No	46	83.6	83.6	100
National	Yes	23	41.8	41.8	41.8
	No	32	58.2	58.2	100
Regional	Yes	9	16.4	16.4	16.4
	No	46	83.6	83.6	100
Another	Yes	24	43.6	43.6	43.6
	No	31	56.4	56.4	100

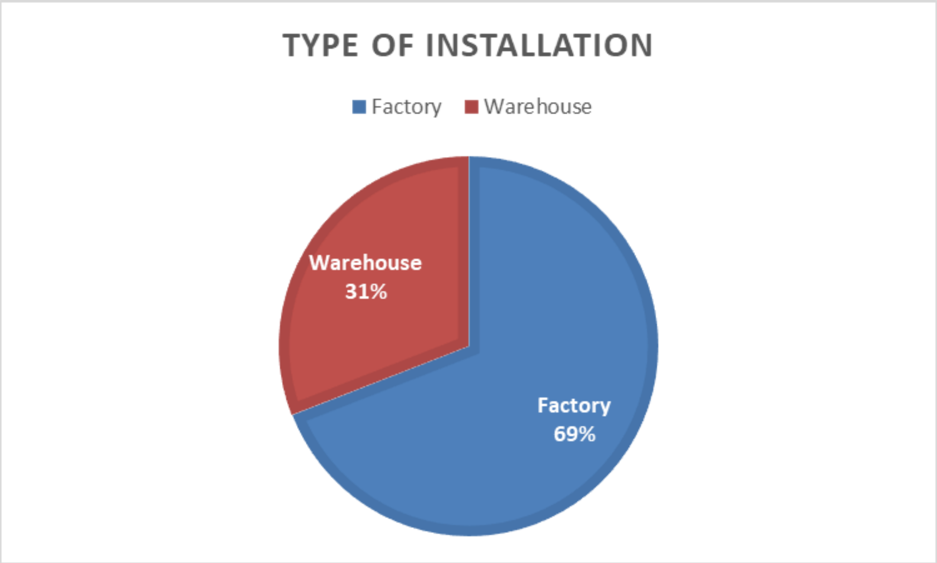


Figure 6: Type of installation

When talking about Small and Medium Enterprises (SME), there is no doubt about their essential function in the Moroccan national economy. They represent the bulk of the entrepreneurial fabric, a proportion exceeding 95% and occupying more than 50% of private sector employees. The share of SMEs in Moroccan exports and domestic private investment is respectively around 31% and 51%. These entities play a vital role in promoting the social dimension as well as in the economic and territorial development.

The SME is present in all sectors of Moroccan economic activities: industry, crafts and construction, businesses and services that include tourism, communications, transport, financial services, ...In the industrial sector in particular, the SME accounts for almost half of the total as follows: textiles and clothing (35%), chemistry and para-chemistry (26%), agri-food (24%), mechanics and metallurgy (12%), electrical and electronic (3%) (MAITIA, 2008).

According to the Moroccan Ministry of Industry (Ministry of Industry, Morocco, 2018), the most influential industrial sectors in the national economy are: the automotive industry for that Morocco is considered as the first construction hub on the African continent, followed by other sectors such as Aeronautics, Textile; Leather, Electronics, Electrical, Chemical-Parachemistry, Pharmaceutical, Building Materials, Renewable Energy and Mechanical and Metallurgical Industries (IMM). This explains the rations and sectors related to the hazardous substances involved in this research. Not all the companies that answered the questionnaire are specialized in handling of hazardous materials. About one fourth (21.9%) of the obtained answers comes from companies belonging to other industries whereas the other half comes from related companies of different sectors.

The figure 7 shows the percentage of companies whose part of their activities at the site is related to HM

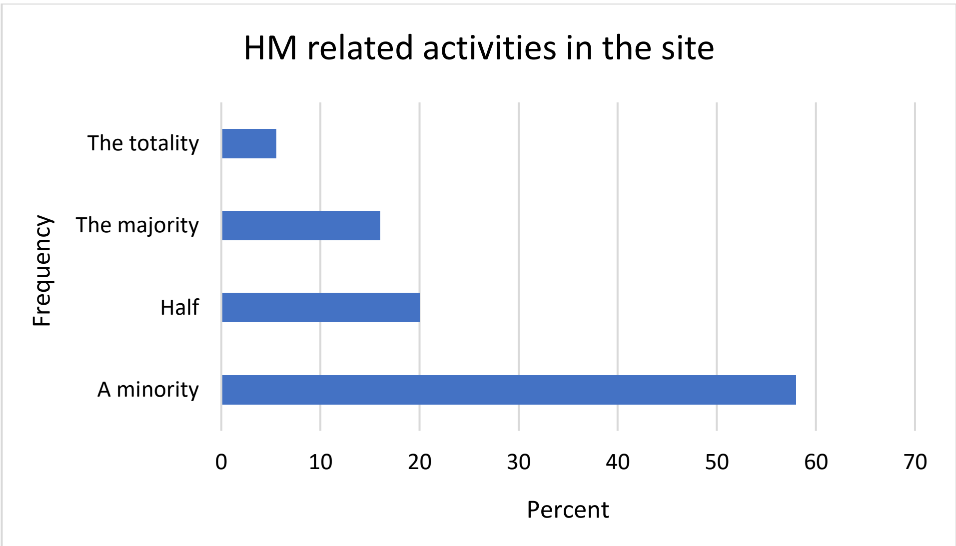


Figure 7: HM related activities in the site

We have found that there are various classes of HM on the site of the median company where most present classes are the flammable liquids (56.4%), the gases (40%), and the corrosive matters (29.1%). The rarest classes are the radioactive materials (7.3%) (figure 8).

Among the various dangerous substances listed on the sites, one is generally found: Gasoline, GPL (Butane), Sulphuric acid and Xylene.

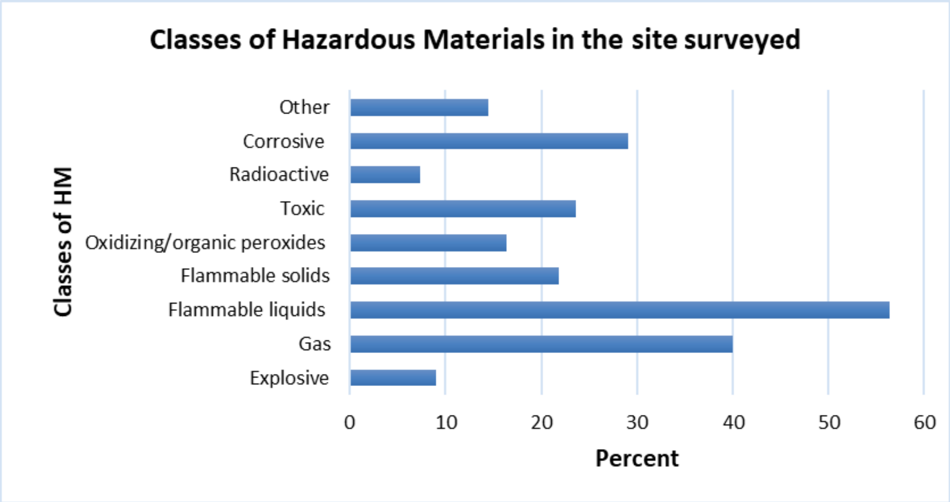


Figure 8: Classes of Hazardous Materials in the sites surveyed

Concerning the classes of Hazardous Materials imported or exported through the port of Tangier Med in 2017 (TMSA, 2017), we have noted, based on some received statistics, that the most transported classes, as shown in Figure 9, are as follows: the flammable liquids (36%), corrosive matters (19%), the gases (40%).

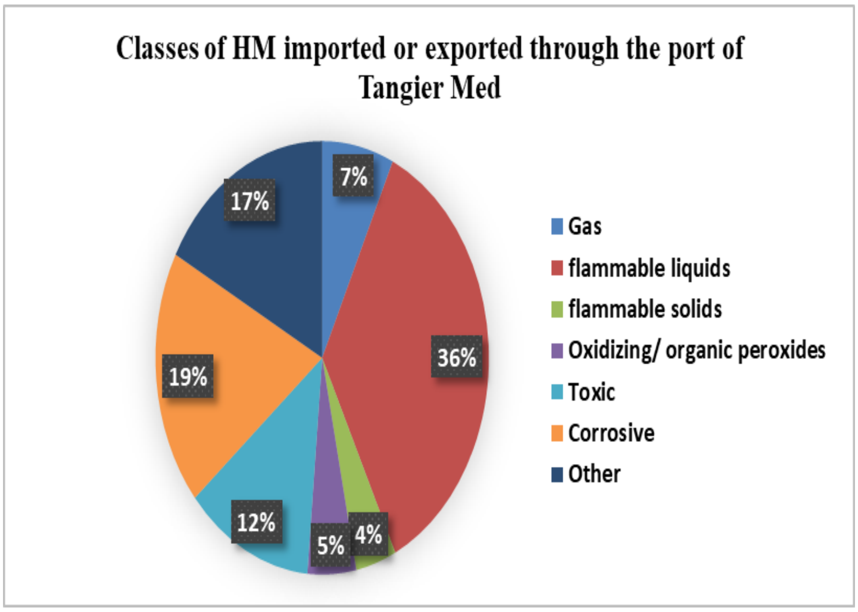


Figure 9: the classes of Hazardous Materials imported or exported through the port of Tangier Med in 2017

Concerning Class 1 (Explosive) and Class 7 (Radioactive Materials), their presence constitutes small percentage due to the special procedures used to transport the materials of these two classes, which require the approval of a special commission to be imported, exported or transported. In (Gouvernment of Morocco, 2011), some examples of the procedures used in the port national agency for these two classes depending on the Moroccan law have been cited.

❖ ***<u>Explosive material cases:</u>***

- All ships carrying explosive substances must stop in the port and wear a red flag (bravo) during the day and a red light at night, until the berthing green light issued by the competent authority time and date of docking of the vessel;
- The distance separating two vessels, one of which contains Class 1 goods, must be at least 50 meters. The distance separating two ships containing explosives must be at least 100 meters;
- The parking of class 1 goods is not allowed neither at the store nor on solid land;
- The parking time of goods at the dock, while loading or unloading, must be kept to a minimum;
- The guard (fireguard) is mandatory throughout the duration of the operations, it is the user's responsibility of users. The designated custodian will be responsible for monitoring all fire hazards (cigarettes, spark, fire, etc.) that could occur at a distance of 30 meters from the vessel or cargo. It must also prohibit access on board to any foreign person;
- Finally, he must warn the port authority in case of fire or explosion or risk of fire or explosion;
- Ships carrying explosives in transit may be permitted to handle other non-dangerous goods at a berth station assigned to general traffic.

❖ **Radioactive material cases:**

- Any vessel handling a radioactive source at the port, no matter how small, must request it at least a week in advance from the port authority;
- Vehicles will be allowed to enter the port only if the packages are accompanied by a certificate from the exporting country indicating the nature of the radioactive source and its activity, stating that the packing and stowage comply with the regulatory requirements of the OMI;
- The vessel may perform its loading or unloading operations at a berth destined for the traffic of general cargo provided, however, the distance separating the radioactive source from other vessels must be at least 60 meters;
- The goods must only dock at the time strictly necessary for loading or unloading;

- Before entering the port, a radioactive material specialist at the public health radio station at the user's expense must board the equipment equipped with measuring devices to ensure that the radioactivity of the packages does not show any signs of radioactivity. danger for handling. He will also have to carry out a systematic control of this radioactivity throughout the duration of the operations;
- A guard at the expense of the users have to prohibit to any person foreign to the port, access to a distance of 60 meters of the zone where the packages are.

II.2.2. Provisioning and forwarding

The great majority of the guarantors (70.9%) affirm receiving HM or products controlled on the identified fixed site. and just 27% of the companies that make the shipment of HM or products controlled from their site as shown in the following graphic:

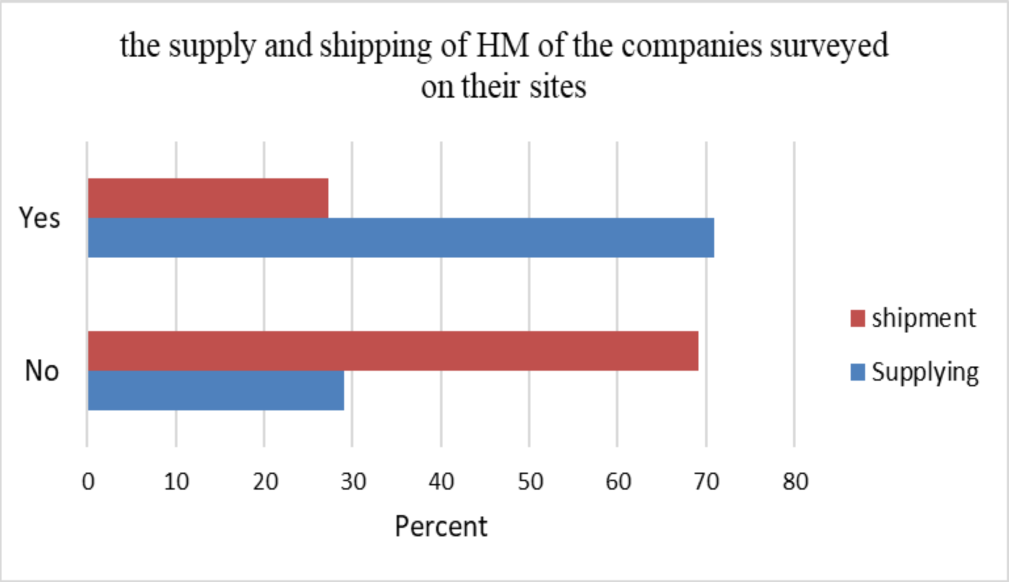


Figure 10: the supply and shipping of Hazardous Materials of the companies surveyed on their sites

This is explained by the presence of companies consumers and non-producers of HM within the sample. The majority (27.3%) of the companies affirm the treatment of five different dangerous substances or more (figure 11). The very great majority of the companies (79.8%) receives dangerous substances during the month, the week or few times a year.

In contrast, we found the majority (10.9%) of 25.5% of companies affirming the shipment of hazardous materials from their sites, averred that they treat five different dangerous substances or more. The very great majority of the companies (28.6%) ship dangerous substances during the day, 23.8% during the month or a few times a month, 19% during the week (figure 12).

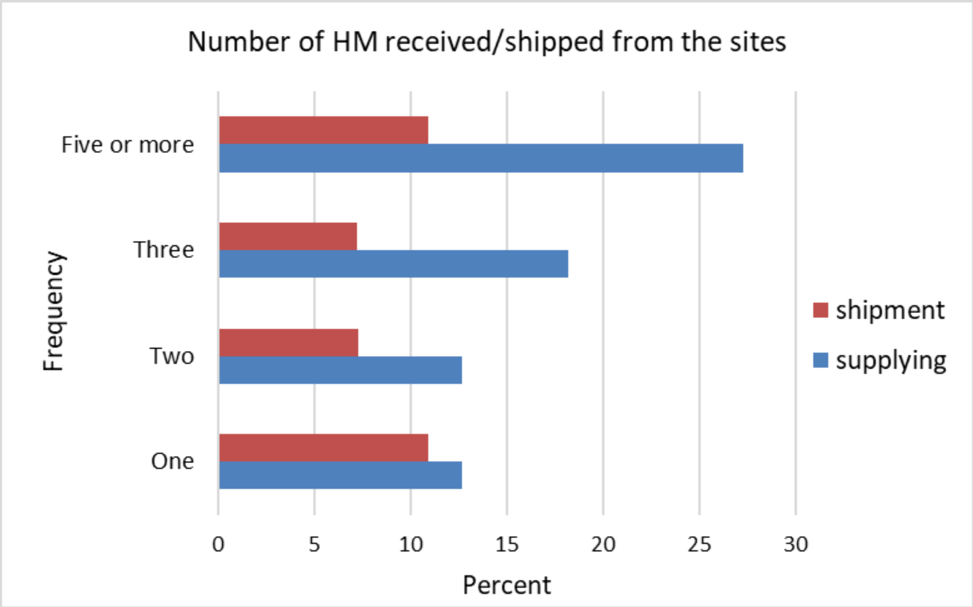


Figure 11: Number of Hazardous Materials received/ shipped from the sites.

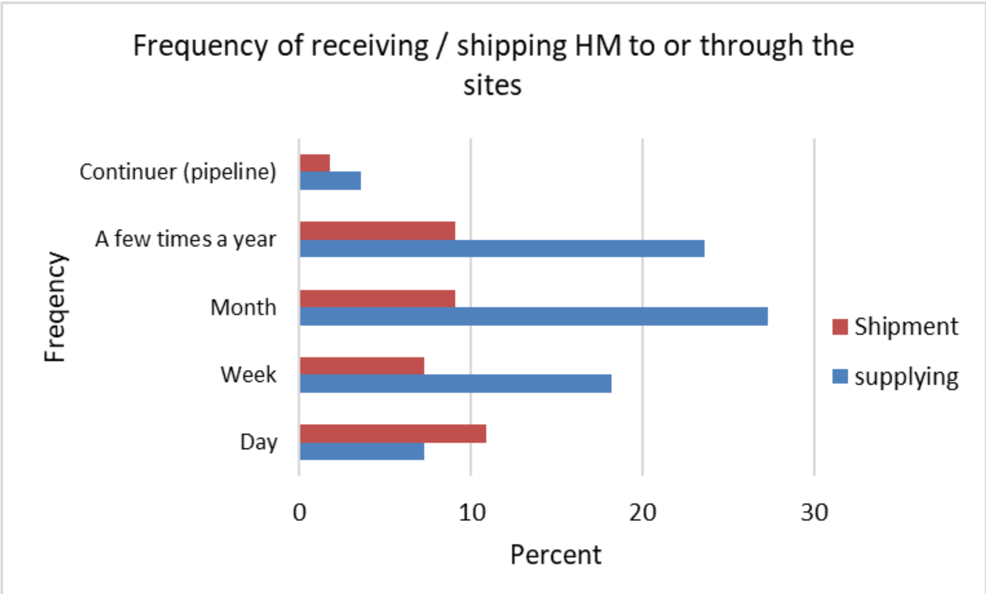


Figure 12:Frequency of receiving/shipping HM to or through the sites.

The means of transport preferred for the provisioning are, respectively (figure 13): the truck (74.5%), the train (5.5%), the boat (27.3%), pipeline (3.6%) and the plane (1.8%). The strong preponderance of the truck can surprise at first sight, but recall that according to the questionnaire, a company would notch this choice recourse to a means of transport, even if it is in an occasional way. The percentages collected cannot thus be translated into mileage, tonnage or a number of sending. We have also found that the most common mode of transportation is the conditioned mode (67.3%), which bulk transport just 18.2% of respondents who affirmed who are using its use.

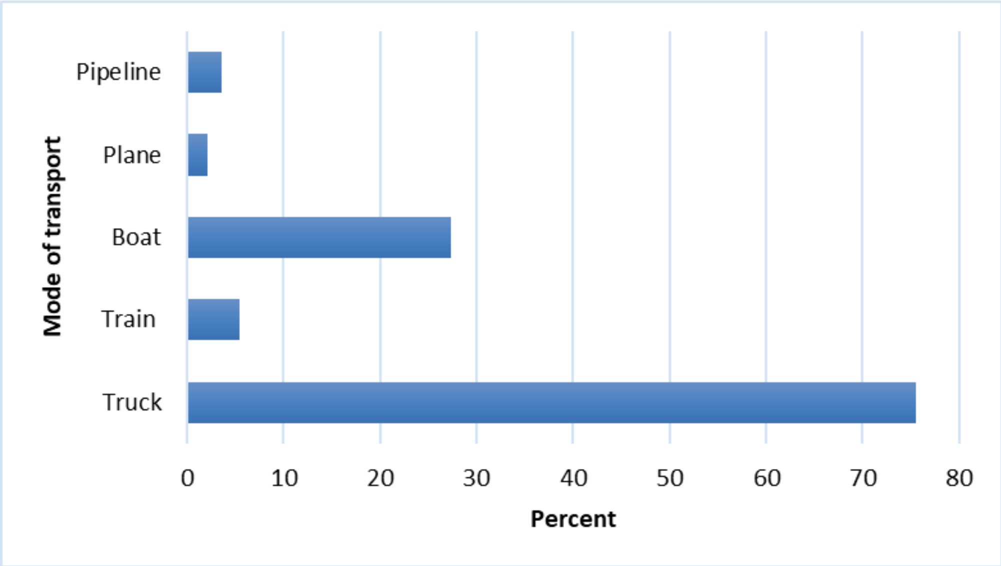


Figure 13:mode of transportation used to transport HM

A high number of companies affirm that it would be impossible to change means of transport. The majority of the other companies affirm that they could change means of transport only for some substances but not for all the substances. It should be recalled here that the choice of a means of transport is largely influenced by the proximity of the infrastructures of transport.

Very few companies (12.7%) carry out truck transport on their own. This task is usually assigned to the supplier (41.8%) or to a third-party carrier (23.6%) (Figure 14). However, the majority of the companies supervise the unloading of the dangerous substances (41.8%) and in many cases carry out unloading (21.8%). There are on the other hand some companies that uses a subcontractor (5.5%) (figure 15).

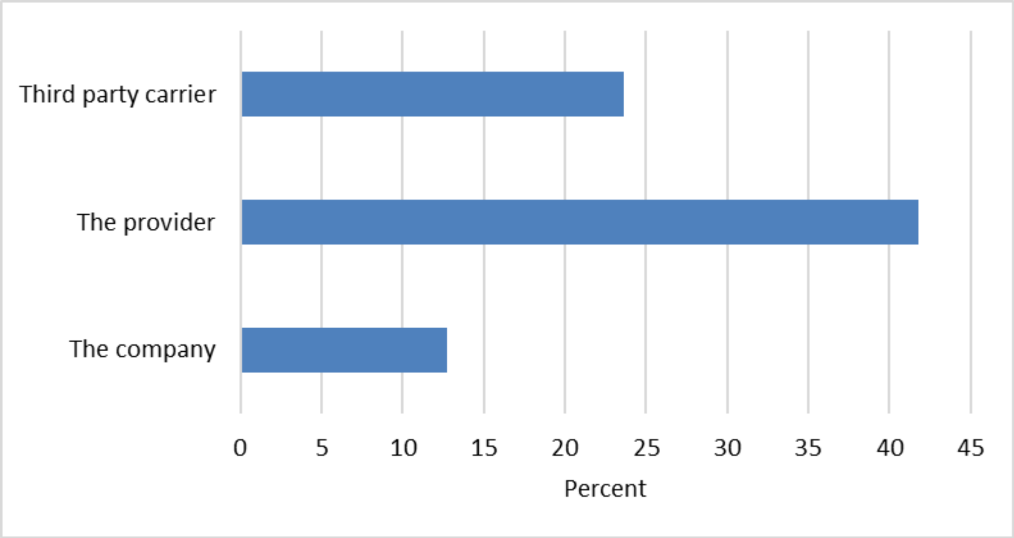


Figure 14: responsible for truck transport

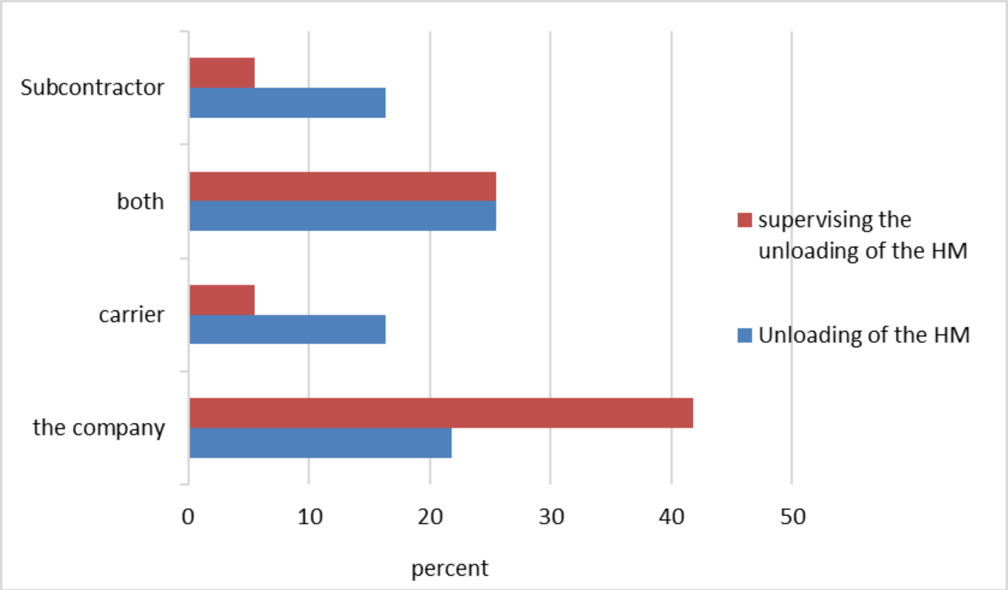


Figure 15: Supervising the unloading of HM or HMR in supply

II.2.3. Hazardous Materials (HM) at fixed site

The training offered to the employees working with the quays of shipping/receiving is often offered by a consultant (39.2%), yet the majority (56.4%) of the employers are concerned too, as shown in figure 16. This training is often offered during the recruitment (47.3%) or even annually (47.3%). Among the surveyed companies only (3.6%) announce that they offer this training in three years (figure 17). The other companies include it with other trainings sessions at the time of recruitment or with the requirements.

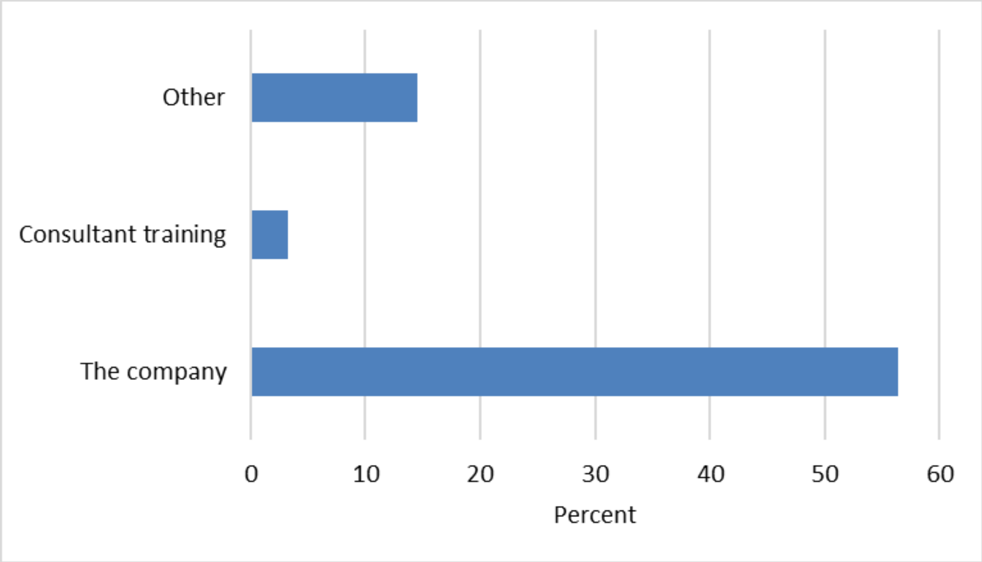


Figure 16: The training offered to the employees of the shipping/receiving.

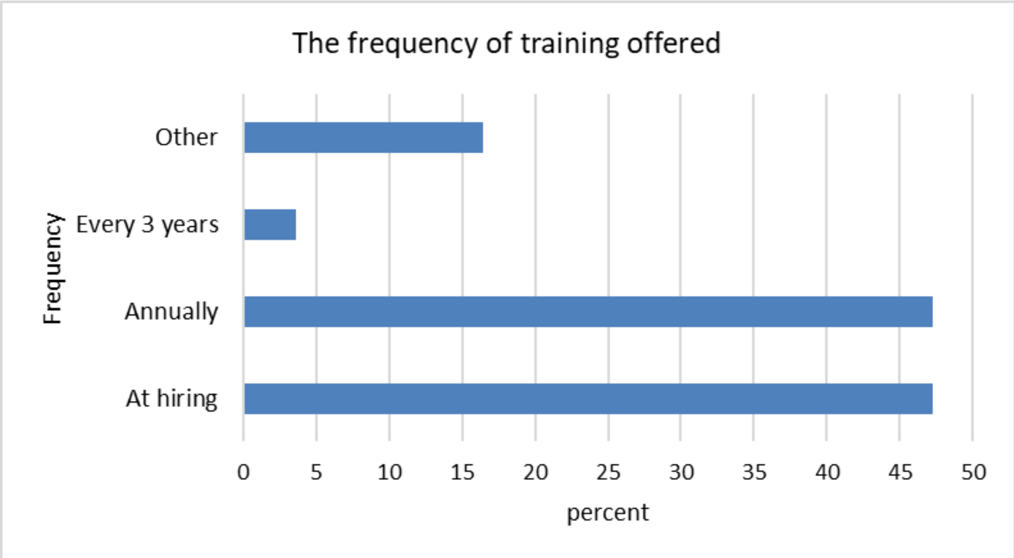


Figure 17: The frequency of training offered to the employees at site.

The majority of the companies (54.5%) always or often use zones dedicated to HM. Some companies however affirm that they're used only sometimes (10.9%) or even rarely (10.9%). In the opposite way, it is not frequent that dangerous substances are stored in a temporary way on the site of the company. A few companies (21.8%) have even stated that they often if not always have recourse to this practice.

On the other hand, temporary storage outside the site is not very widespread. Only 16.3% (3.6% always, 12.7% sometimes) of the companies use temporary storage on a site which does not belong to their own company, whereas temporary storage on other sites belonging to the company touches 18.2% of the guarantors (5.5% always, 12.7% often).

The majority of the companies affirm that they transport HM more often in order to avoid having too much of it on the site. A considerable share of the companies (65.5%) affirm that they have recourse to this practice always (12.7%), very often or sometimes (52.8%), whereas 21.8% of the companies say that they never do it, as shown in figure 18 below. This contributes to the increase in the number of convoys on the roads, although the quantities remain the same.

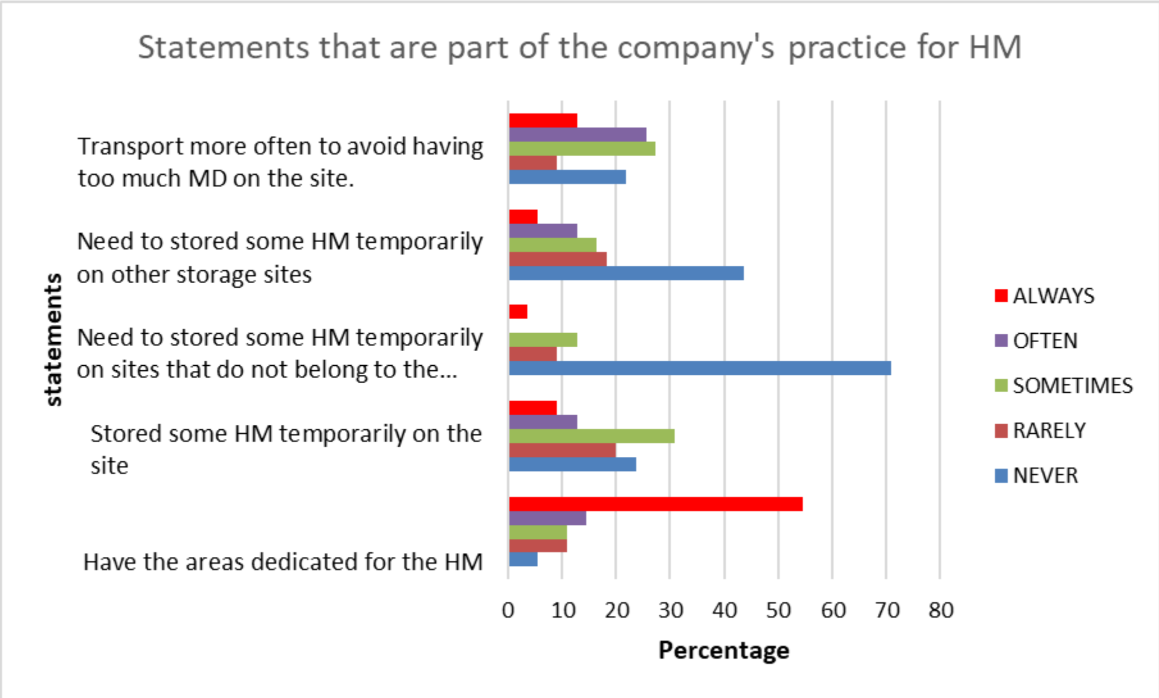


Figure 18 :Statements that are part of the company's practice for HM.

II.2.4. Costs related to HM supplies and shipments

The majority of the companies (85.5%) are ready to invest more in safety since the sums do not exceed a certain level. In the vast majority of cases, this level is below 5% (for 20% of them) or even 10% (for 14.6% of companies that have answered) on current operating costs (figure 19).

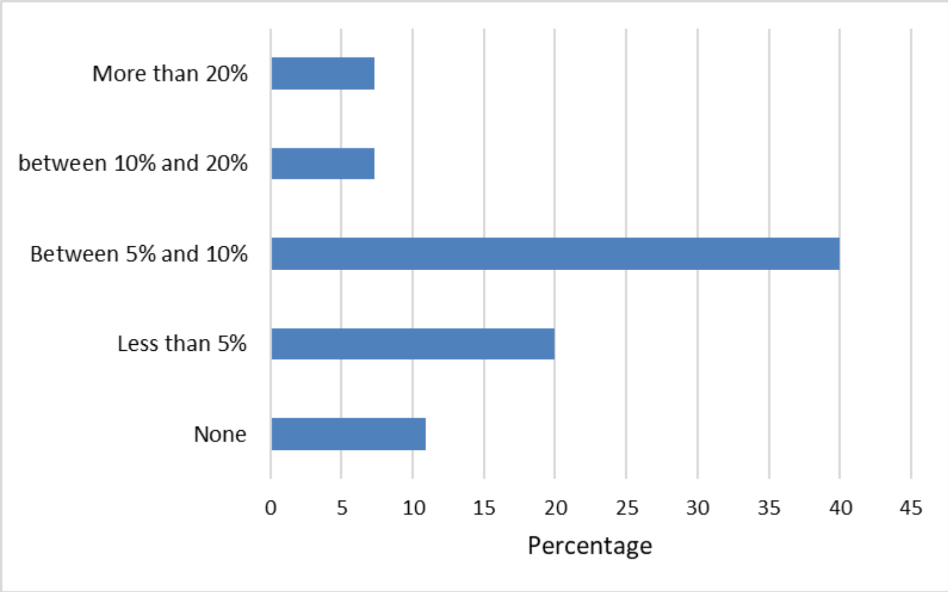


Figure 19: percentage of operating costs that companies would to invest for security measures.

Moreover, when they make their choices of provisioning or HM forwarding, the criterion "Transport security" is mentioned very often (89.1%) followed by the "cost of transport" (83.6%) then the "cost of storage" (70.9%) as shown in figure 20. Several companies did not classify their answers in order of importance, but even with fragmentary results, this classification offers a distribution similar to the one mentioned so far.

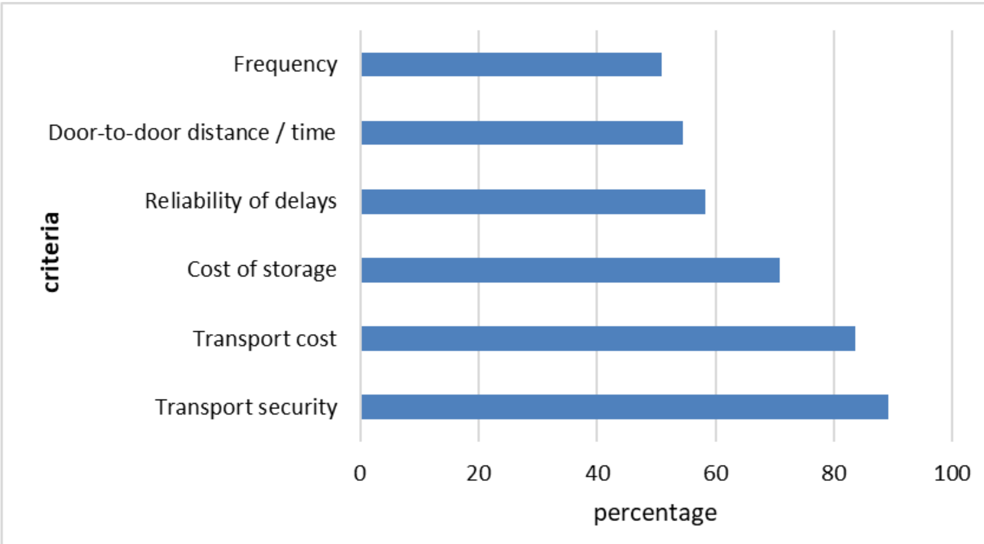


Figure 20: the criteria that are important when the company makes its choice of MD supply or shipments.

The most frequently mentioned Hazardous Materials items when referring to costs as shown in figure 21 are, in order: equipment on the site and employee training (74.6%), security audits (69.1%), specialized vehicles (67.4%), regulatory measures (65.5%), General insurance premiums (56.4¨%) and hiring of a security manager (52.7%). The insurance premiums (52.7%) and the accidents/incidents HM (49.1%), are less often mentioned.

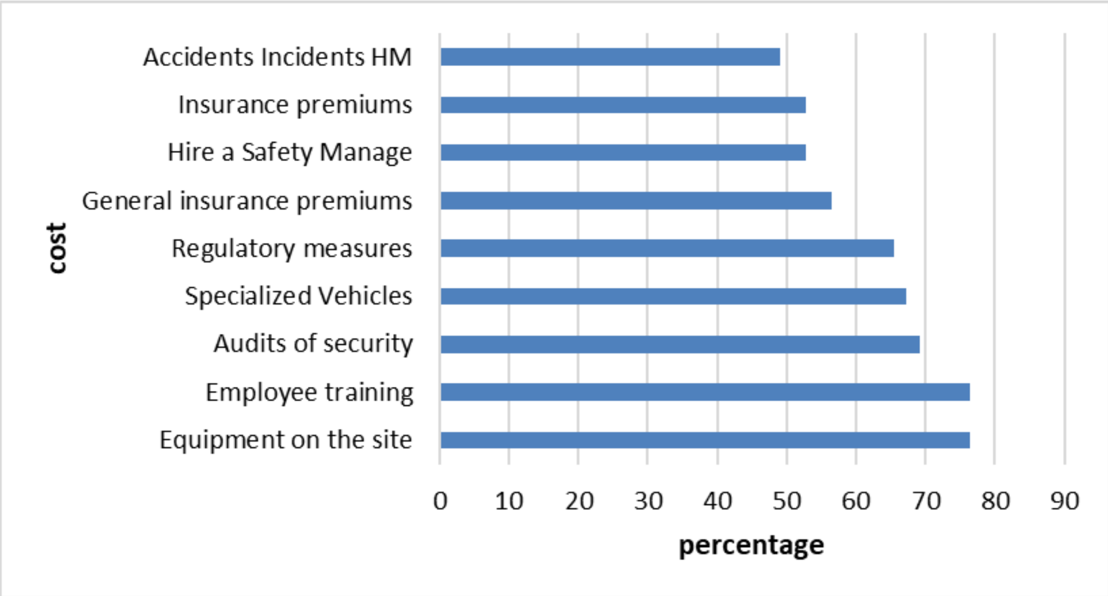


Figure 21: The costs incurred by HM represent a significant burden for the company.

The guarantors had to consider the economic impact of three types of accidents (with spill, implying employees, implying the public) compared to the economic impact of an accident isolated without discharge. In the three cases, the companies have estimated that the impact would be more important, and their evaluation of the possible impacts on their company increases with each new scenario. Indeed, 16.4% of the guarantors have estimated that the impact would be much more important for an accident with spill whereas this proportion grows to 32.7% for an accident involving employees and to 36.4% for an accident involving the public. We have noticed, however that some guarantors have estimated that the impact would be similar if the accident implied employees or the public (figure 22).

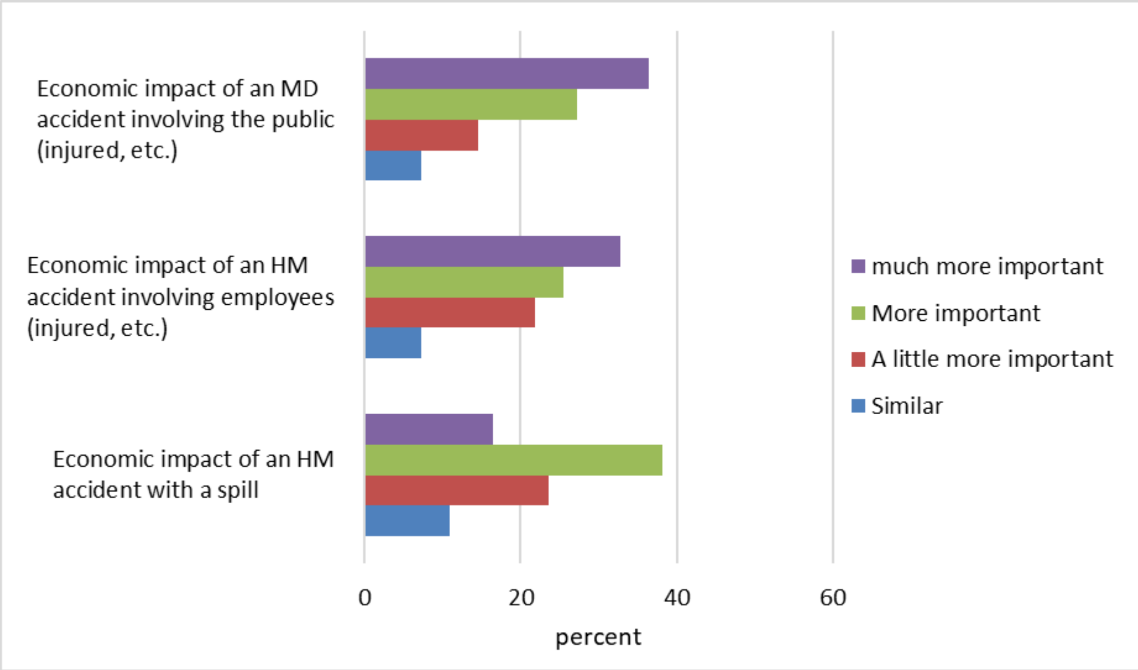


Figure 22 : the economic impact of an MD accident on the company.

II.2.5. Subcontractors with activities related to HM

All companies use subcontractors for any of their Hazardous Materials activities. The areas where they are most popular as shown in figure 23 are, in order: transportation (45.5% supply and 34.5% shipping), loading (40.5%) and unloading (34.5%). On the other hand, a few companies use the services of subcontractors on their site, whether while handling (27.3%), packaging (25.6%), storing (18.2%) or producing (18.2%).

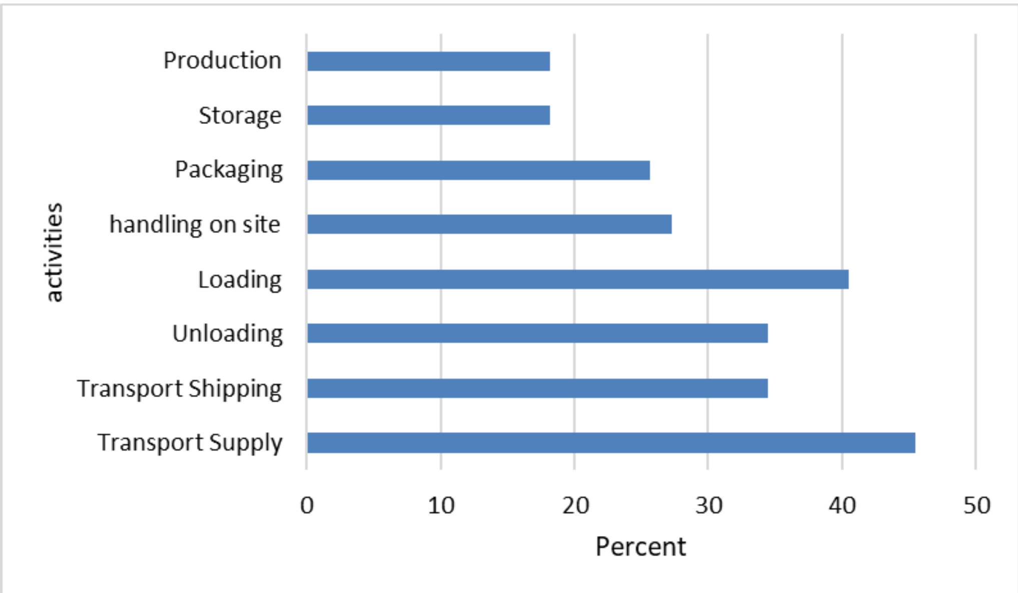


Figure 23: subcontractors in HM activities

Regarding the use of subcontractors for transport, companies mainly cite: the fact that they do not have the expertise (23.6%) and the fact that the carrier shares the responsibility of the risk (25.5%), the costs (16.4%) and the fact that they do not have vehicles (9.1%) as illustrated in figure 24 below. Conversely, the most cited reasons for not using subcontractors are risk management (32.7%) and costs (14.5%) or other reasons (23.6%).

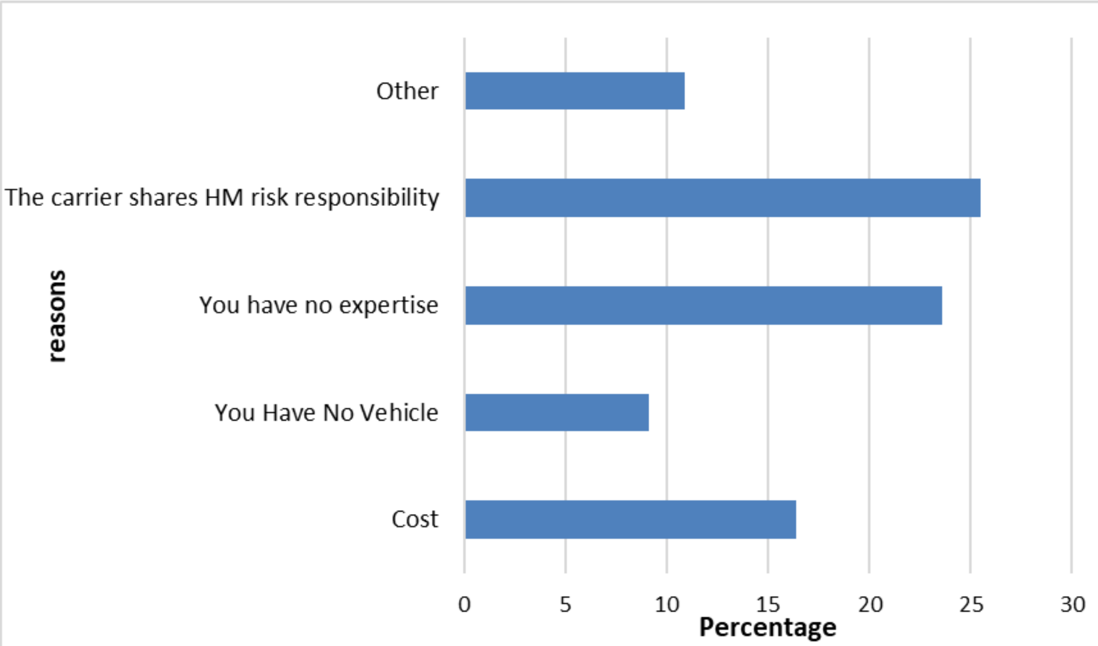


Figure 24: reasons for using the subcontractors in the transport activities.

A number of elements point to a tendency towards disempowerment. For example, several respondents have claimed that the impact of a transport accident made by their subcontractor would have a zero impact on their company (20%) or lower (25.5%) than an accident, with their own vehicles. Besides, 25.5% have said that they never perform safety audits of their subcontractors while only 20% have stated that they always do. When we combine these few elements with the fact that 16.4% of the companies know perfectly well that their subcontractors delegate in their turn to subcontractors (29.1% ignore it and 5.5% are vaguely aware of it), one can easily realize the extent of the phenomenon of disempowerment in transport.

Regarding the contracts of these companies with their subcontractors, 10.9% of respondents still use long-term contracts with their subcontractors while 21.8% have mentioned that they never use them (Figure 25). When it comes to the selection of the subcontractors targeted by these contracts, companies are mainly concerned with: reliability / quality of service (72.7%), control of safety (70.9%), cost (69.1%), ISO certifications (60%), the ability to track transportation (52.7%), carrier reputation (50.9%) and past accidents (50.9%). The possibility of establishing a lasting relationship (45.5%) receives less attention, although they are also considered important by many companies (figure 26).

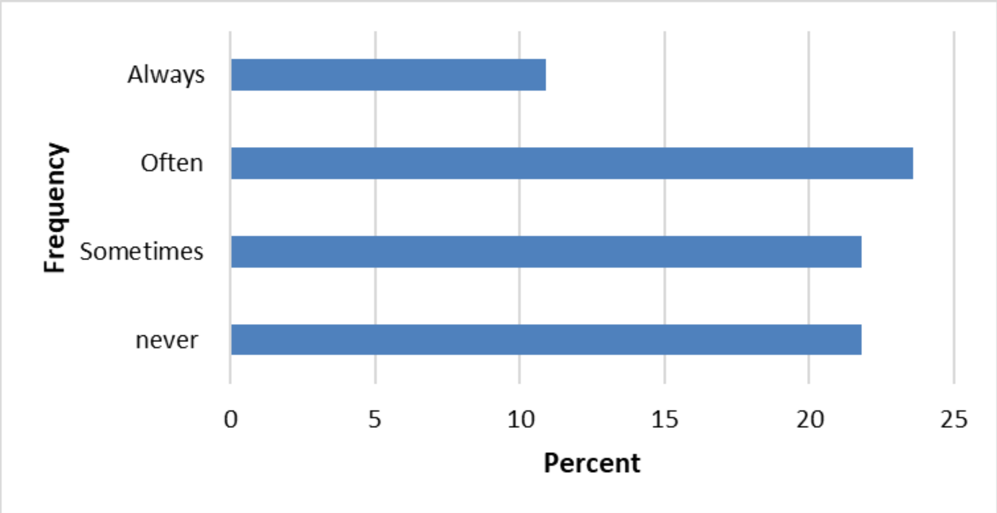


Figure 25: Long term contracts between the company and their subcontractors.

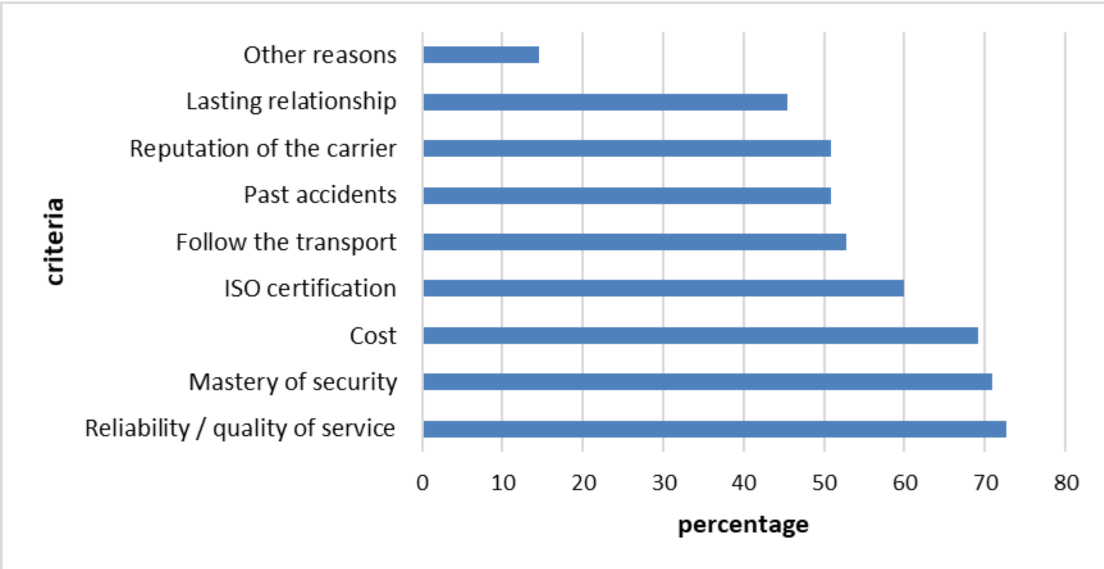


Figure 26: The relevant criteria while selecting a carrier for HM

II.2.6. Risk management

Almost all companies report performing risk analyses on their site, in spite of numbers such as never (7.3%) rarely (7.3%) or sometimes (16.4%). On the other hand, they are less likely to do risk analyses for transportation; a number of companies never do (16.4%), rarely (10.9%) or sometimes (21.8%) and only 21.8% always do, unlike 34.5% in fixed site. This is because a large number of companies outsource transportation activities. Similarly, companies are more likely to have stricter procedures than the law on their site for transport (23.6% still use more stringent procedures than the law on the site, against 16.4% for transport). Additionally, few companies (18.2%) use tracking technologies (GPS, etc.) to transport HMs (40% never use them) (figure 27).

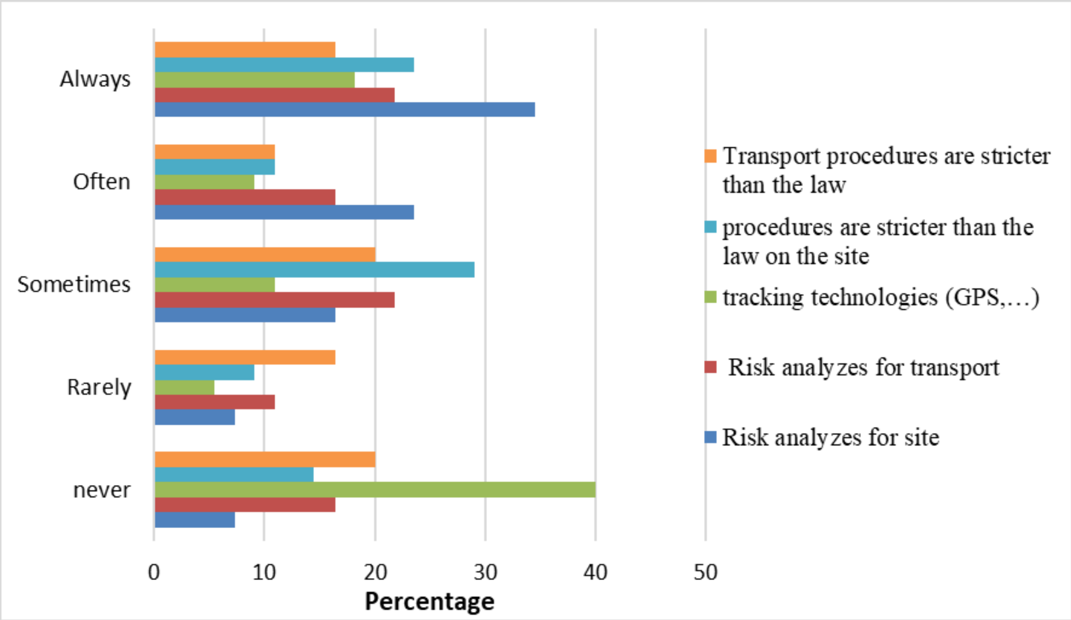


Figure 27: Risk management for the surveyed companies

A few companies communicate their risks with citizens, whether for their site (12.7% always do it) or for transport (7.3% always do), but many companies use their risk management to enhance their image with 29.1% of respondents who have said that they never do it, as shown in figure below.

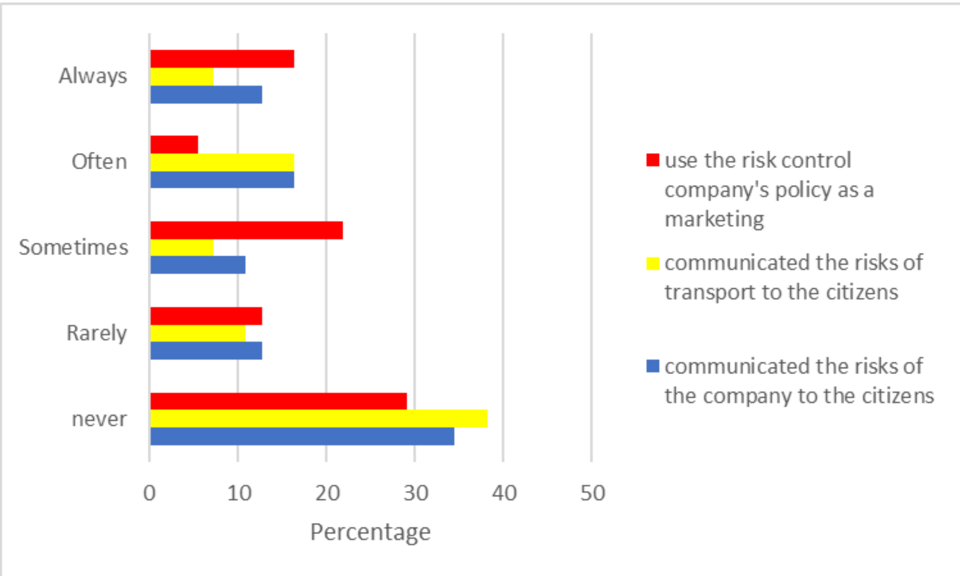


Figure 28: Risk communication in the surveyed companies.

The majority of respondents (52.7%) still claim that they use specific procedures while loading and unloading HMs. Though, some companies never use them (16.4%), rarely (3.6%) or sometimes (16.4%). On the side of the various risk management programs, we have observed the same situation. Most companies offer risk management information/communication sessions to their employees (69.1%), have a workplace health and safety committee (69.1%), and have dedicated risk management staff (61.8%). %), or a prevention program specific to MD (61.8%) (figure 29).

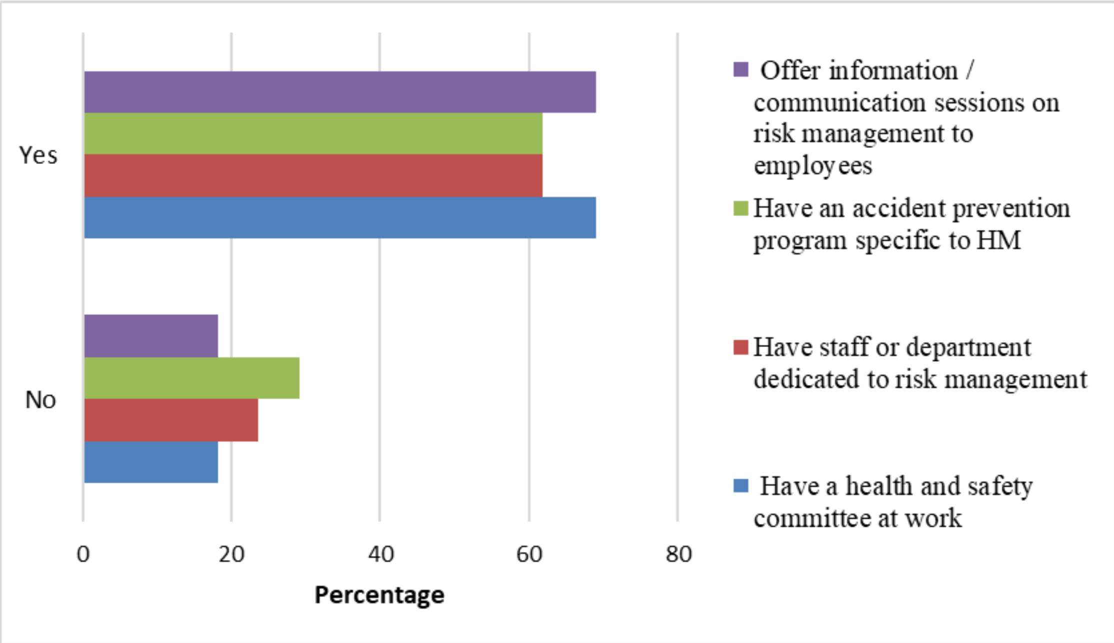


Figure 29: Risk management programs in the surveyed companies.

When the companies are questioned about the possible impacts of an HMs accident (in transport or on the site) on their company, the companies answer respectively, as shown in figure 30: the direct cost (70.9%), the loss of image (65.5%), the loss of production (65.5%), the loss of customers (60%), the increase in insurance premiums (58.2%) and the reaction of citizens (45.5%).

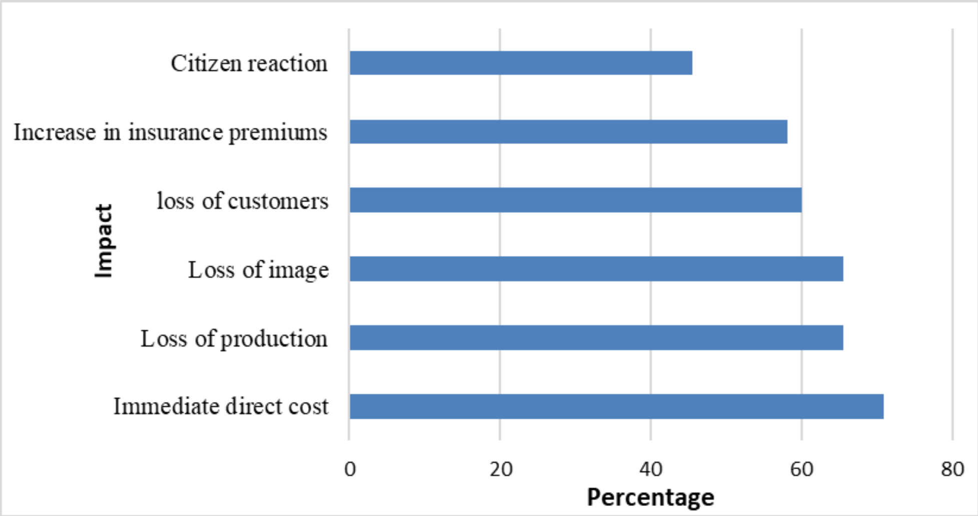


Figure 30: The possible impacts on the company in case of HMs accident

Most companies (56.4%) still list these accidents in a register, although 7.3% of respondents say they never do so and 3.6% rarely do. In the same way, 60% of the companies always carry out investigations following these accidents whereas 3.6% of the companies affirm that they never do it. (figure 31).

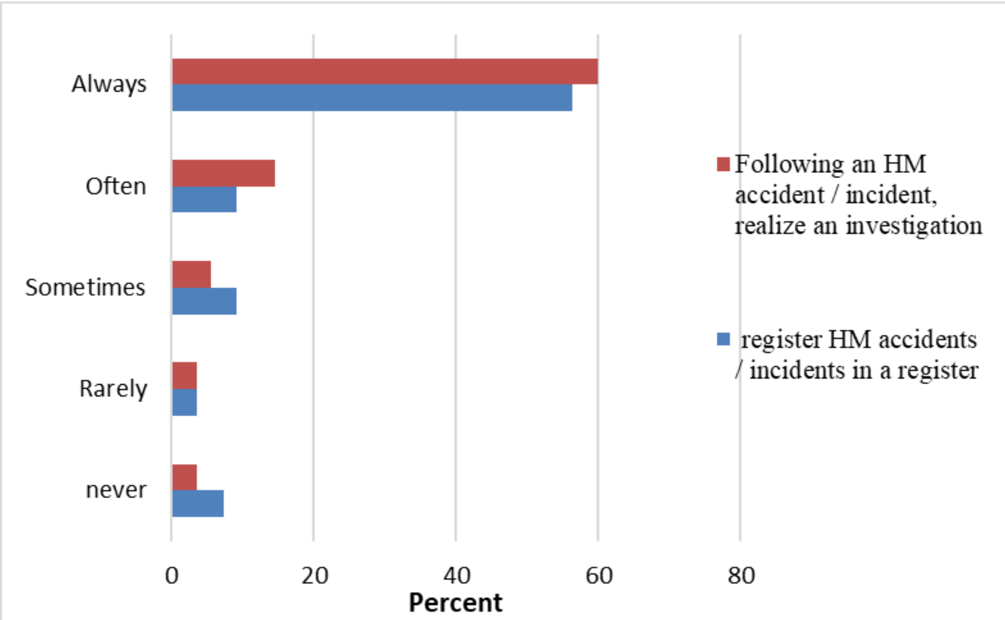


Figure 31: Accident/incident management for the surveyed companies.

In the opinion of many companies, a fixed-site accident (49.1%) would have a greater impact than a transport accident (18.2%), as shown in figure 32.

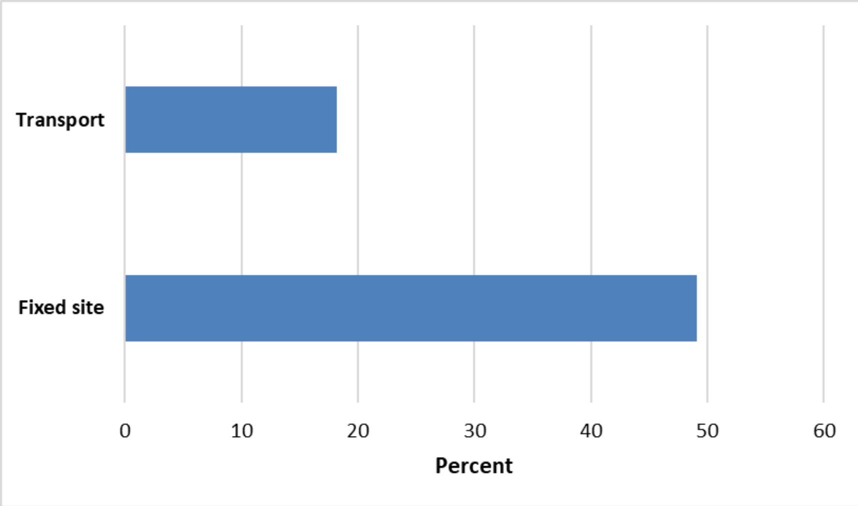


Figure 32: Type of HM accidents and their weight on the companies.

II.2.7. HM Regulation (Law No. 30-05 on the transport of dangerous goods by road)

Many companies claim that MD regulations (site, transportation, health and safety) restrict their day-to-day activities with only 23.6% of companies saying they never limit them. Storage regulations seem to be the one that restricts businesses the most. On the other hand, 30.9% of companies say that Health and Safety at Work regulations never limit them and 29.1% of companies say that transport regulations never limit them (figure 33). It should be remembered, however, that the majority of companies do not perform the transportation themselves, which may influence their perception of transportation regulations.

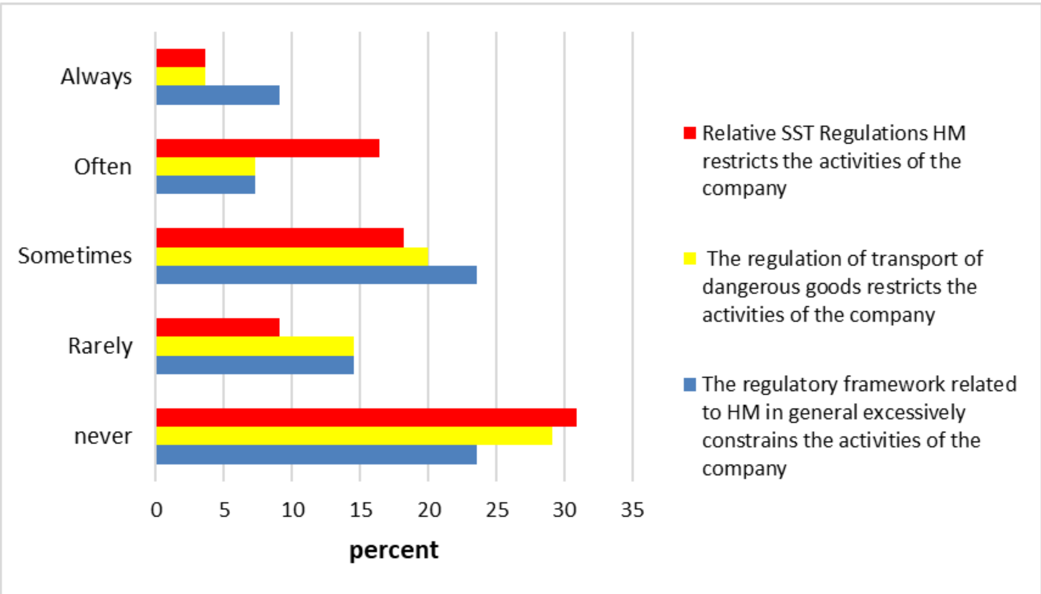


Figure 33: The affirmations related to the HM regulation according to the surveyed companies.

Due to the limitations imposed by the storage regulations, several companies had to: make substitutions of materials (54.6%), reduce their stocks of HMs (61.9%) or change their logistical choices and delivery frequencies (52.7%).

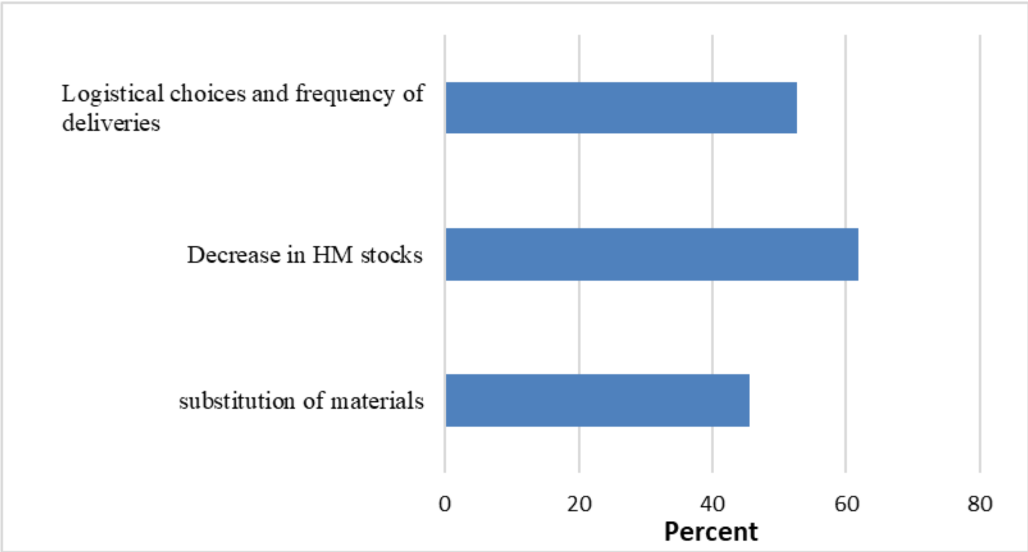


Figure 34: the choice of modifications that can be made by companies according to HM storage regulations.

Our primary objective is based on the development of this part of the study by examining the nature, quantity and routes of HM in circulation in Morocco. Unfortunately, while we were doing this research, there was a lack of information and statistics on HMs even among the services and state agencies. As a result, it was difficult to formulate a coherent and precise idea on this question at the national level. That can be attributed to several reasons, the most important of which is the absence of an exhaustive official inventory of HM currently circulating in Morocco, only a few fragmentary statistics are available. They are carried out in the places of production and consumption without indicating the precise nature of the substances transported.

The classification adopted by Morocco is that developed by the UN. When examining the data from our survey, we can conclude that the classes of the most dangerous substances transported in Morocco are flammable liquids, gases and corrosive substances (figure 8), so the transport administration must be aware the danger of major accidents that may occur by:

- fires and / or explosions caused by flammable materials;
- serious disorders related to inhalation or ingestion of certain toxic substances Etc.

The industrial sector ranks second in the Moroccan economy (HCP, 2018), so the range of dangerous products, which are mainly manufactured products in circulation, is not very wide. The hydrocarbon sector and its derivatives are the ones that accounts for the majority of safety concerns related to hazardous substances transported. This sector is important on the national scale, with two respects:

- the preponderant and vital role of hydrocarbons in the country's economy;
- the largest volume of hazardous substances carried is that of hydrocarbons and their derivatives.

The hazardous substances produced (re-imported) and transported locally come from several industrial branches of which we quote the most important:

- **the Petroleum sector:** this sector is almost exclusively confused with the oil terminals of the Tangier Med port, Jorf Lasfar port and Mohammedia port..., which store and distribute substances considered to be among the most dangerous. They are all the more so since their circulation is daily, massive and embracing the whole national territory with a higher concentration in urban agglomerations.

The most frequently transported materials in this sector are liquid fuels, gases, LPG, etc.;

- **the industrial gases sector:** are various chemical materials and often dangerous. It contains liquid air and its main components (nitrogen, oxygen, argon, etc.) but also nitrogen proxy and medical gases;
- **the sector of inorganic chemicals** such as acids and various inorganic compounds whose degree of dangerousness is high;
- **the organic chemicals sector** including all petrochemicals and carbochemicals such as organic alcohols and acids, cyclic hydrocarbons, etc.;
- **The Industrial Chemicals sector**, which supplies the market with special lubricants, activated mineral materials and various preparations for welding, knock-downs, etc .;
- **the agrochemical sector:** which is illustrated by the manufacture of insecticides, pesticides, herbicides and all the well-known phytosanitary products;
- **the nitrogen products sector**: also known for their dangerous nature because of the materials they contain, such as ammonia, nitric acid, nitrates,
- calcium cyanamide, etc. It is also this sector that manufactures nitrogen or phosphate fertilizers;
- **the explosives sector:** probably the most dangerous hazardous material in the event of an accident during its transport, or simply of its handling. For example, propellants, occasional explosives, pyrotechnics are some of the substances that are manufactured in this sector;

- **the paints and varnishes sector:** This is an industrial sector that uses and produces dangerous substances such as solvents, paint removers, varnishes and, of course, paints intended for all uses;
- **the plastics sector:** it is by far the most developed in Morocco. He is one of the major consumers of dangerous substances. We can mention the different polymers, resins, polyesters, silicones, etc.

Other very high-risk branches should also have been mentioned if they existed in Morocco. This is the case for nuclear materials such as uranium, thorium and other highly dangerous compounds and radioelements in the event of an accident.

Hazardous substances imported or produced and distributed in Morocco mainly use the road to reach their destination (Figure 13), the mode which represents more than 75% of the national freight (Ministry of Economy, 2013).

The analysis of accidents caused by hazardous materials, as indicated in (Vilchez et al., 1995) have shown that these accidents are significantly highly occurring during the transport of theses HM, followed by accidents occurred in processing plants and storage facilities. In contrast, most domino accidents are found in storage area, followed by process plants and transportation (Darbra et al., 2010), which are mainly caused by LPG, petrol and gasoline (Darbra et al., 2010).

Road transport of hazardous substances has the advantage and the convenience of directly linking the producer and the consumer. In this case, the quantities transported packaged or in bulk, are relatively less important (a few tons to a few tens of tons). This also allows, at least in theory, to reduce the risk of accidents by minimizing the handling and unloading-loading operations. Moreover, users of dangerous substances can be scattered throughout the national territory. In fact, the majority of companies that produce or use as raw material the dangerous substances are concentrated in Casablanca and its surroundings and also the region of Tangier. Nevertheless, this is not a safety advantage as accidents in urban and suburban areas can be particularly disastrous.

The fact that Morocco has a fairly large network of national roads and interurban highways is an asset for the road transport of dangerous substances. Most of the accidents in which they are involved are generally due to vehicle failures and especially to the imprudence of the transport professionals.

Among the dangerous products transported are flammable liquids, gases and corrosive substances, which is represented in (Shen et al., 2014) as the most frequent hazmat tanker accidents. The rarest materials are radioactive materials (Figure 8).

Even if the increase in the number of tankers used to transport oil and other dangerous substances is justified by the ever-increasing demand for these products, which are essential for economic activity, the fact remains that this activity generates a multitude of potential dangers (fires, explosions, intoxications, negative impacts on the environment).

The constraints of competitiveness and productivity imposed on industrial, mining and agricultural stakeholders, mean that the transportation of these products to the exploitation sites is carried out at a frantic pace and generally without much precaution. Moreover, the multiplicity of the risks of pollution and the various other dangers that this field of transport provokes is often unpredictable, to the point that in the event of an accident, these risks took the appearance of a catastrophe not only for the environment but also for users (the populations).

For example, the accidental spillage of flammable, explosive or highly toxic products is always the most dangerous because the damage caused would be disastrous.

Unlike the road network which covers the entire national territory, the rail network for the transport of HM is limited to Atlantic Morocco with two axes serving the Northeast (Oujda) and Central West (Casablanca) respectively. A good part of this network is reserved for the transport of phosphates.

With the recent development of passenger transport, the Moroccan railway does not offer a large place for goods in general, and even less for dangerous goods. The ones it is accustomed to and continues to transport are always connected to phosphate (phosphoric acid, sulfuric acid, fertilizer). Explosives are also among the dangerous substances carried by the railways. The administration of ONCF applies strict regulations on them, and no major accident has ever occurred.

The transport of dangerous goods by rail was regulated by the Dahir n° 1-01-223 of 30 August 2001, confirming the ratification by Morocco of the Convention concerning International Carriage by Rail (COTIF) and its appendix on the transport of dangerous goods better known. also, under the initials RID (Moroccan government, 2002).

In terms of risk management, the results show that 47.3% of companies received hazardous materials training for the entire supply chain during recruitment and thereafter on a yearly basis (Figure 16). So, the majority of companies expressed their willingness to supply security equipment and almost all companies have shown that the choice of HM supply or shipments is based primarily on the criteria of transport security (89.1%) and transport cost (83.6%) as shown in Figure 20.

The data analysis also highlighted some specific characteristics. Most accidents are due to operations such as the loading / unloading of HM as indicated in (Darbra et al., 2010), these operations as shown in our research (Figure 23) are dedicated mainly to the subcontractor, it seems that an additional effort should be devoted to improve the security of these procedures, including stricter legislation and better training.

It is remind that the decree of application of the law 30-05 relating to the road transport of the dangerous goods was published in the Official Bulletin on June 30, 2011 (Gouvernment of Morocco, 2011).The law fixes the conditions of security imposed on the carriers and envisages sanctions and sentences d imprisonment ranging from one month to two years and fines of DH 2,000 to DH 100,000. In order to align with European standards for road transport of dangerous goods, in particular the European Agreement on International Transport dangerous goods by road, known as ADR. Law 30-05 determines all the conditions applicable to this type of transport: from loading to unloading, from the conditions of use of the vehicles to the obligations incumbent on the operators in the operation.

Though Morocco is among the first signatory countries to these agreements, the application of these agreements is not yet widespread because of lack of implementing legislation. As a result, with the exception of oil companies and multinationals, most tanker drivers do not distinguish between a potato load and radioactive or explosive material. Several Moroccan companies organize ADR training for the benefit of their drivers and can travel in Europe without any problem to transport dangerous goods on European soil. There is no point in passing a law if it is not applied in the field. What we are seeing now is that some customers are not demanding and always favor the cost factor at the expense of security.

Several accidents caused by tanker trucks had serious economic, social and environmental consequences. Since 2007, the Bouregreg Watershed Agency has sued two carriers for accidentally spilling part of their oil load. The first directly in the wadi Bencheqcheq and the second, near the wadi Amiran in the region of Bouznika. "*The cleaning operations cost 220,000 dirhams and we ask the authors of the pollution damages*"(EL ARIF, 2014).

Nowadays, there is a real gap between multinationals whose number remains limited and local businesses which are likely to be more numerous. Multinationals with significant resources are more compliant with safety standards for the transport of dangerous products and substances. Local operators, on the other hand, are relatively less sensitive to the importance of these standards. But, we still lack application texts. In the absence of these texts, professionals do not apply fortiori the regulatory provisions. By contrast, multinationals apply the standards of their parent companies while local companies do not apply the regulations. The change in this situation that threatens to give rise to a disaster at any time in the event of an accident requires a real awareness on the part of professionals and decision-makers.

Conclusion

This study presents the results of a survey on logistic choices related to hazardous materials in Morocco. it focused on the determination of the nature of these hazardous materials, in terms of classes of materials transported, frequency of supply and shipment, etc, and then identified the most used organizational security practices by Moroccan companies.

This study undertakes to determine the situation of hazardous materials in Morocco, we tried to give an analytical and holistic analysis for the whole transport logistic chain of these HMs.

Organizational and technical security measures need to improve through the introduction of a culture of safety throughout the HM chain of shippers, handlers, carriers and consignees of HMs, who must therefore receive training adapted to their field of activity and their level of responsibility especially for classes (classes 3, 2 and 8) as well as the high presence in the Moroccan industry sector and which have the highest risk in case of accident.

The results obtained in this research can help the interests involved (authorities, professionals and companies) for strategic and operational planning of the transport chain of dangerous products in Morocco.

The exploratory research we have conducted can pave the way for a wide variety of development perspectives. It might be interesting to extend this survey to the kingdom as a whole in order to highlight possible discrepancies in the use of organizational security practices.

Among other things, the possibility of developing a guide to good practices for carriers to inform them of the practices they can put in place to reduce their risk, or the possibility of making many recommendations to different ministries in relation to the training, the use of equipment, accident register policies, or even mount communication campaigns to raise awareness of the risks of multi-client carriers and multiple loading / unloading operations.

Chapter III: Risk analysis for hazardous material transport by road: Case study on Tangier-Tétouan region, Morocco

Partially reproduced from: Soussi et al., “Risk analysis for hazardous material transport by road: case study on Tangier-Tetouan region, Morocco. IEEE 13th Annual Conference on System of Systems Engineering (SoSE), pp. 464-470. 2018, June.

Introduction

Quantitative risk assessment (QRA) is a methodology which estimates the risk proposing a quantitative evaluation by joining incident consequences and frequencies estimation (Hassan et al., 2009). Risk is well defined as "a measure of economic loss, human injury, or environmental damage in terms of both the incident likelihood and the magnitude of the loss, injury, and damage" (CCPS, 2000). Quantification of the risk by the combination of accident probability estimation and consequences models for accidental events which involve hazardous material (hazmat) products represents the main important issues in the risk-averse routing problem for hazmat vehicles (Bersani et al., 2010). In a general, the transportation risk analysis (TRA) has been presented by a three-dimension approach as proposed in (AIChE/CCPS, 1995). TRA integrates the goals, the complexity of the study and the level of detail of the analysis. The user can perform a limited, generalized or detailed set of risk estimation and, contemporary, he can carry out a qualitative, semi quantitative, or quantitative risk analysis.

In other words, QRA represents the main detailed analysis based on consequence, frequency, and risk estimation in the framework of TRA.

The practical application of those well-known procedures to compute risk evaluation, due to interrelationship among different subsystems involved in hazmat transportation problem, gives rise to difficulties. For a System of System (SoS) perspective, different components characterize this problem: vehicle, driver, transported hazardous material, infrastructure, external conditions, and exposures can affect risk analysis evaluation. Besides also different players such as manufacturers, carriers, logistics operators, public authorities and emergency responders have different roles in the hazmat risk management. Often the interaction among such SoS components increases complexity in the hazmat risk assessment.

From a technological viewpoint, the prevention of the risk in automotive systems is realized by passive and active safety technology. The first technology refers to the interactions among components of the vehicle to protect occupants during a crash. Besides, active safety technology mainly refers to system which assists in the prevention of a crash (e.g. Antilock Braking System - ABS). Some more recent devices shift the attention towards physiological alterations of drivers. In this respect, human behavior observation during a transport process is another important component closely related to safety.

Tracking/tracing vehicles technology has already become a prerequisite for the vehicle safety with important application to hazmat transport.

From an analysis viewpoint, the different subjects involved in the hazmat transport require a methodology which simply, but qualitatively and quantitatively, shows how the interaction among these systems and the variation of some parameters may lead to an accident. Moreover, end users would like also to know how it is possible to detect and forecast these accidents, and how it is possible to modify the route to minimize the maximum exposure of population to the accident risk, which is in turn function of the interaction of the different systems. A wide range of literature is available from academic and industrial sources to realize a QRA in hazmat transportation framework taking into account the different components of the risk computation.

The main purpose of this paper is to present a QRA dedicated to hazmat road transport based on simplified approach for the frequency and consequences analysis. Usually, a QRA needs to carry out the frequency and consequence analyses which represent two critical steps in the risk evaluation. Those analyses should identify all relevant hazards covering the complete range of potential incident taking into account the conditional probability of the consequences arising given the occurrence of a hazmat accident. The proposed simplified approach provides the hazmat transport operators and public authorities with relevant data about risk estimation with a limited effort in the collection and computation of data. The frequency analysis will be realized by considering preselected event tree schemes for hazmat product. The consequences analysis will be based on an expeditious method (APAT, 2006) to compute the hazard distance to identify the impact area for different accident scenarios.

I. CCPS guideline for QRA approach

A full-scale QRA application should require the following sequence of sub-steps (CCPS, 2008).

1. Determination and classification of possible scenarios: this step consists of identifying each hazardous material movement, the method of transport chosen, also the route and route segments covered during the transport;

2. Data collection for frequency analysis: reliable data about accident and non-accident rates, failures equipment, spill or release probabilities, container designs, other factors influencing probabilities of hazardous outcome have to be collected. Reviews of public and private studies, review of literature in scientific context, stakeholders and carriers’ comments and other sources have to be consulted;

3. Selection of consequences measure: this step provides estimation of the consequences that accident scenario could give rise. It includes also identifying the impact area pertinent for

every possible incident scenario. Type, dimension, and orientation of the release, weather conditions, wind speed, atmospheric stability are the main factors that determinate the size of the impact zone;

4. QRA application. The fourth step implies to perform the generation of the QRA, defining frequency and consequence analysis according to previous step results.

5. Presentation of results. This fifth step provides the presentation of QRA conclusions using standard risk criteria comparison or other benchmarking values to estimate the results.

I.1. Frequency analysis

Frequency analysis implies the computation of two main components: the probability that the undesirable Initiating Event (IE) may occur and the Probability of Hazmat Outcome (PHO) after the IE. The hazard outcome case represents the physical manifestation of the incident scenario i.e. jet-fire, pool fire, or toxic cloud in case of toxic product transportation. The frequency analysis for IE includes the computation of the estimated accident rate (per year) for the specific logistic operation. The task to compute the accident rate requires a large amount of accident data. When accident data for each selected road section is not available, in order to obtain statistically significant information on frequencies, usually statistical data coming from international or national accident database are used. On the other hand, the computation of the PHO case happened after an accident, needs to identify a number of possible accident scenarios for each hazmat. Event Tree Analysis (ETA) (Ericson, 2005) is usually used to model PHO according to the frequency of occurrence of different releases. ETA is an analysis technique for identifying and evaluating the sequence of events in a potential accident following the occurrence of an IE. ETA utilizes a graphical logic tree structure known as an event tree (ET). The objective of ETA is to determine when the IE will generate a serious accident or if the IE is controlled by the safety systems or procedures (Clifton, 2005). To complete an ET, the initial release frequency has to be inserted on the initiating branch. In most ETs, the IE produces different pivotal events that usually are modeled as binary. The possible scenarios ensuing from the IE coming from the occurrence or nonoccurrence of the pivotal events. It needs to build the event tree diagram in order to gain event failure probabilities. The PHO for different outcomes is associated with each branch of the ET. Consequently, the risk is computed multiplying the values on each branch of the tree until the root. The probabilities indicated in an ET are dependent on the physical and chemical characteristic of the hazmat spilled product (temperature, pressure or flammability), on the released types, on the amount of the leakage, and the external environment condition. Crash or release from a valve, the structures of the equipment (width, material, shape) produce different accident outcome case.

I.2. Consequences analysis

In the terminology of QRA, “consequence” is a measure of the expected damages of the incident scenarios which effects the “impact area”. This latter is the area over which a particular incident outcome case produces lethal effects, based on specified thresholds, on health (e.g. death, injury, and exposure), property loss, and environment. In this study, only health effect has been considered. The impact area, in detail, indicates the geographical area in which an atmospheric release of a substance would affect the present exposure in a specified time horizon (ERG, 2016). Besides, impact area can be defined also as an estimated area where a hazard (such as toxicity, flammability, thermal radiation, or damaging overpressure) has exceeded a user-specified Level of Concern (LOC). The Level of Concern (LOC) is a threshold value of a hazard (toxicity, flammability, thermal radiation, or overpressure) above which a threat to people or property or environment may exist (EPA, 1987). The PHMSA's Emergency Response Guidebook (ERG, 2016) by U.S. Department of Transportation provides initial isolation distance in case of an accident involving specific hazardous materials and, often, first responders and hazmat decision planners use it.

Another popular model used to calculate the chemical concentration after a release is the Gaussian Plume Model (GPM) (Verma, 2007). Depending on the properties of hazmat, Heavy Gas Model (HGM) is used as applicable instead of GPM (Serrano, 2014).

Other atmospheric dispersion tools based on a geographic information system (GIS) exists to generate the impact area. Area Locations of Hazardous Atmospheres (EPA, 2013), for example, is the hazard modeling program based on the CAMEO® software suite (Aloha, EPA), which is used widely to plan and respond to chemical emergencies. It generates impact zone estimates for various types of incident outcome: toxic gas clouds, flammable gas clouds, BLEVEs (Boiling Liquid Expanding Vapor Explosions), jet fires, pool fires, and vapor cloud explosions. The computation is based on the characteristics of the released product, release behavior, weather conditions, and tank car design information. Finally, the quantification of population exposed, in terms of number of person potentially exposed in case of accident in the impact area, is a fundamental step for the risk assessment. This computation can be realized by elaborating statistical population data available in the latest census published by national authorities or it could be determined through a more detailed GIS analysis. Other sophisticated techniques can be applied based on dynamics of the population in space and time as dasymetric mapping method (Mennis, 2003) or by population distribution data coming from mobile phone user detection (Bersani et al., 2016).

I.3. QRA application

Risk measures that can be computed by the QRA are basically two: individual risk and societal risk. Individual risk is defined as the probability that an average unprotected person, permanently present at a certain location, is affected due to an accident resulting from a hazardous activity. Societal risk represents the cumulative frequency per year that a group of people could be killed by an accidental event in the impact area. It is usually represented by a F-N curve. This curve plots, as a log/log graph, the expected annual frequency (F) of the number (N) of fatalities in the impact area arising from all possible hazmat incidents. In order to evaluate the acceptability of risk associated to a selected logistic operation, ALARP criteria could be used. ALARP criteria, which means "As Low As Reasonable Practicable", proposed in (DNV, 2014), represent a standard methodology to evaluate risk.

II. Proposed QRA method

In the presented paper, the QRA for hazmat transportation by road is based on an approximation of the CCPS guidelines. The author realized a simplified approach in order to allow a less complex risk analysis useful to carry out a basic evaluation of the risk level for a selected hazmat transport activity.

II.1. Frequency analysis in the proposed approach

In the proposed approach, the accident frequency comes from statistical data of accidents aggregated for road network classification, i.e. accident on highway or on route outside or within urban area. Besides, the PHO is generated by multiplying three components:

$$PHO = CRP \times SSD \times PWS$$

where

- CRP, the conditional release probability, is the probability of a release given an accident;
- SSD, the spill size probability, is the probability of different release sizes and;
- PWS, the probability for weather stability, represents probability of different stability/wind speed combinations.

In the proposed model, a limited number of scenarios are preliminarily defined taking into account a limited number of values for the component in (1). Only one CRP value, three different possible spill size probabilities (small, medium and large) for SSD and PSW values for two typical stability classes of meteorological conditions are taken into account for the frequency analysis.

II.2. Consequence analysis in the proposed approach

The identification of the impact area, relevant to each possible outcome case, represents one of the main tasks in the consequences analysis. Many models and tools exist, as presented in the previous section, to estimate the impact area for hazmat accident outcome.

In the proposed approach, the “expeditious” Shortcut Method (APAT, 2006) has been used to compute the impact area using a low number of attributes and parameters (Baldacci, 2004). The method provides, by a simple tabular application, the largest horizontal extent (radius) of the impact area from the point in which the accident takes place. The Shortcut Method aims at estimating the consequences of incidental events related to the storage, handling and transport of hazmat by rail, road and pipeline. The application of the Shortcut Method for hazmat transport by road provides the estimate of the maximum hazard distances of impact for two types of incident events: incident with high probability of occurrence, characterized by limited magnitude, but still relevant; incident with medium probability, associated with more remote occurrence and medium-gravity magnitude, typical of relevant events but still credible. Shortcut method provides the hazard radius according to the four standard thresholds of lethality (high lethal, lethal, irreversible lesions, reversible lesions) and for two average weather conditions (D.5 and F.2 based on Pasquill's six stability classes (PASQUILL, 1961)). This speditive method represents a good alternative to more complex software simulation tool because it guaranties good accuracy requesting a limited number of input data.

In the proposed approach, the impact area has been constructed as a buffer of uniform radius centred in the location of the hazard source. Besides, considering the hazmat shipment over a route as the movement of this danger circle, a band on both sides of the route has been designated. This region outlines the impact area (Bersani et al., 2016). In the proposed approach, the route has to be divided into sections, identifying the type of network and the level of urbanization in the covered area. The selected area has been classified according to average population density values for only three types of locations (rural, suburban or urban area).

Finally, the number of inhabitants potentially exposed is computed by multiplying population density value per area of impact.

III. Case study: application of the proposed methodology on TANGIER-TETOUAN region (MOROCCO)

The proposed case study consists of defining the societal risk for the hazmat transport by road in the Tangier-Tétouan region, in Morocco. This specific location has a growing freight traffic due to the importance of the Med Tangier Port (MTP) in the context of the Mediterranean Sea, with special interest to hazmat transport. Port Tangier Med represents a global logistics hub, located on the Strait of Gibraltar, and connected to 174 global ports. It might provide a yearly capacity of 9 million containers, 7 million passengers, 700.000 trucks and 1 million vehicles.

Tangier Med is an industrial platform for more than 800 companies representing an annual turnover of € 6,400 million in various sectors such as automotive, aeronautics, logistics, textiles and trade (TMSA, 2018).

In details, two different paths to transport gasoline by trucks between Med Tangier Port (MTP) and Tangier (TA) are considered and compared in terms of risk. The Kingdom of Morocco is a country located north-west Africa. It is bordered by Atlantic Ocean at west, by Straits of Gibraltar and the Mediterranean Sea at north. Tangier Tétouan region, located in the northern Morocco, is characterized by a sub-humid Mediterranean climate due to the presence of Atlantic and Mediterranean winds. There are two types of predominant winds: the western Atlantic wind, which is prevailing blows in November and March from the North-West to the South-West; the Mediterranean east winds that often blow in warm seasons from the East to the North-east. Wind speed reaches an average between 2 and 6 m\s. Otherwise, in 30% of the cases, the wind blows between 7 and 14 m\s. Finally, in the rest 20% of the cases, it is less than 2m\s. However, the above 15m\s wind speed is exceptional (1%) (TMSA, 2018). The proposed case study concerns the gasoline, GPL and, Chlorine transport between Med Tangier port and Tangier, and between Med Tangier port and Tétouan by road.

Statistically, more than 1 Million of tonnes of hydrocarbon has been transferred covering this area by truck. The 7% of the hydrocarbon transported on roads in the selected region consists of gasoline: this means, according to (TMSA, 2018), about 70.000 Ton every year and, consequently, 1750 shipments per year.

Due to lack of statistics concerns the transport of Chlorine and Butane between the Tangier Med port and the Tangier-Tétouan region, we estimated that more than 1000 tankers transport Butane per year, and around 800 trucks transport chlorine. per year between the routes studied.

Figure 35 shows the two alternative paths for the presented case study from Med Tangier Port to Tangier. The first route option (Path 1) to reach Tangier for the MTP has length 69.4 km, and it consists of national and highway road, which cover urban, suburban and rural area

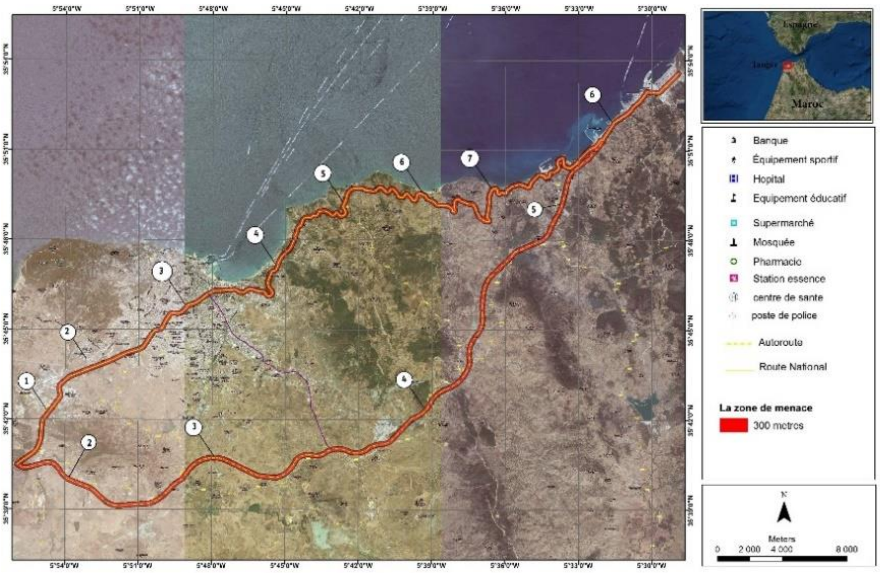


Figure 35: Path 1 and Path 2 selected to transport gasoline from Med Tangier Port (MTP) to Tangier (TA) by truck.

The length of the alternative route (Path 2) is 54.77 km completely on national road, which covers urban, suburban and rural area (Table 24).

Table 24: Parameters for Path 1 and Path 2.

path	Route	Length (Km)	Population class	Road class
Path 1	RN16	13.20	Suburban	State road
	A4	51.87	Rural	Highway
	RN1	4.30	Urban	State road
Alternative Path 2	RN16	13.20	Suburban	State road
		28.04	Rural	
	RN1	13.54	Urban	State road

Figure 36 shows the two alternative paths for the presented case study from Med Tangier Port to Tétouan. The first route option (Path 1) to reach Tétouan for the MTP has length 79.18 km, and it consists of national and highway road, which cover urban, suburban and rural area.

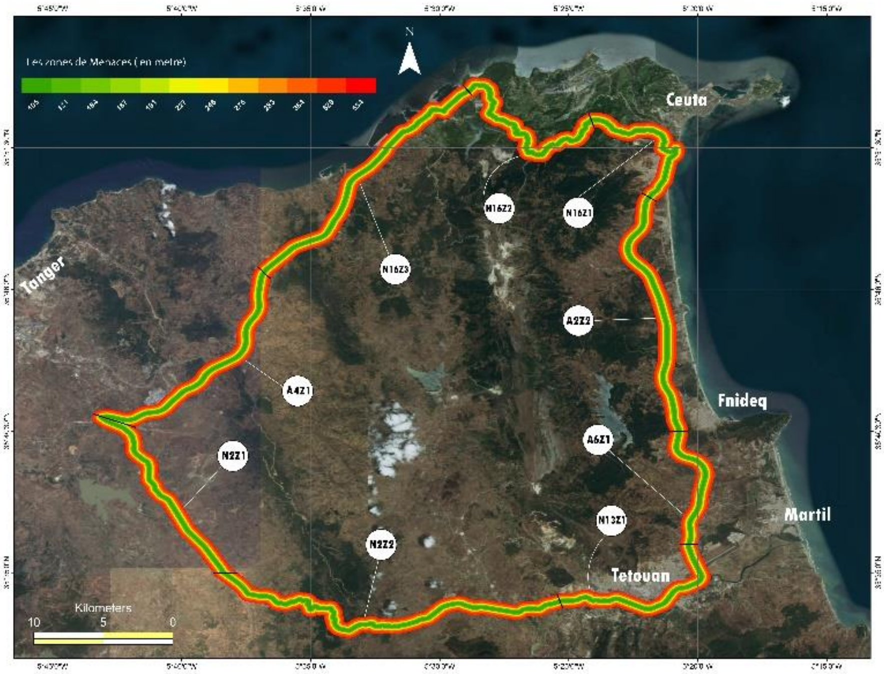


Figure 36: Path 1 and Path 2 selected to transport gasoline from Med Tangier Port (MTP) to Tétouan by truck.

The length of the alternative route (Path 2) is 61.81 km completely on national road which covers urban, suburban and rural area (see Table 25).

Table 25 Parameters for Path 1 and Path 2 for Tangier Med port to Tétouan case study:

path	Route	Length (Km)	Population class	Road class
Path 1	RN16	13.20	Suburban	State road
	A4	17.97	Rural	Highway
	RN2	38.59		State road
	RN1	9.42	Urban	State road
Alternative Path 2	A6	21.22	Suburban	Highway
	RN16	12.58	Rural	State road
	RN16	10.70	Urban	State road
	RN13	11.32		

III.1. Frequency analysis for the case study

The values of road accident rates come from historical records, reported by Moroccan Ministry of Equipment, Transport, and Logistics. This source provides the following data:

1) Number of accidents occurred per year per road class (Highway, State, National and Provincial network) per 100.000 circulating vehicles;

2) Total extension of each road class network on the territory.

The values of the accident rate for each class of transport network in Morocco were as shown in table 26. The path route segmentation finds six different sections for the Path 1 while Path 2 consists of seven sections. Two different road classes (Highway and State road) and three population classes (Urban, suburban and rural) has been considered for Path 1. Path 2 consists of only one road classes (State road) and three population classes (Urban, suburban and rural). Route details for the Path 1 and 2 for each case are listed in the table 27 to 30.

Table 26: Accident rate for road transport in Morocco.
Source (TMSA 2018)

Network transport	**Accident rate [N /(vehicle.km)]**
Highway Network	1.904E-07
State Network	4.016E-07
Regional Network	1.789E-07
Provincial Network	1.582E-07

Table 27: Details of the road segments for path 1 (Tangier).

PATH 1			
Segment	**Length [km]**	**Road class**	**Population class**
1	13.20	State Road	Suburban
2	9.17	Highway	Rural
3	11.37	Highway	Rural
4	17.00	Highway	Rural
5	14.37	Highway	Rural
6	4.30	State Road	Urban
TOTAL	**69.40**		

Table 28: Details of the road segments for alternative path 2 (Tangier).

PATH 2			
Segment	**Length [km]**	**Road class**	**Population class**
1	13.20	State Road	Suburban
2	6.77	State Road	Suburban
3	9.00	State Road	Rural
4	6.00	State Road	Rural
5	6.27	State Road	Rural
6	7.87	State Road	Urban
7	5.67	State Road	Urban
TOTAL	**54.77**		

Table 29: Details of the road segments for path 1 (Tétouan).

PATH 1			
Segment	**Length [km]**	**Road class**	**Population class**
1	13.20	State Road	Suburban
2	17.97	Highway	Rural
3	13.68	State Road	Rural
4	24.91	State Road	Rural
5	9.42	State Road	Urban
TOTAL	**79.18**		

Table 30: Details of the road segments for alternative path 2 (Tétouan).

PATH 2			
Segment	**Length [km]**	**Road class**	**Population class**
1	12.58	State Road	Rural
2	10.70	State Road	Urban
3	18.09	Highway	Suburban
4	9.13	Highway	Suburban
5	11.32	State Road	Urban
TOTAL	**61.82**		

III.2. Consequence analysis for the case study

In the proposed approach, the Shortcut method has been used to compute the hazard radius and, consequently, the impact area. Anyway, in order to guarantee that this expeditious method provides relevant data, a comparison with the results coming from a software tool application to simulate accident scenario is provided to the readers.

The Areal Locations of Hazardous Atmospheres (ALOHA) tool and the Shortcut method has been applied to generate impact area of an accident on road involving a gasoline tank track. The data required to model the accident outcome case with Aloha software appear in Table 31.

Table 31: Data required by Aloha to simulate hazmat scenario for the case study associate to Gasoline, Chlorine and Butane transport on road.

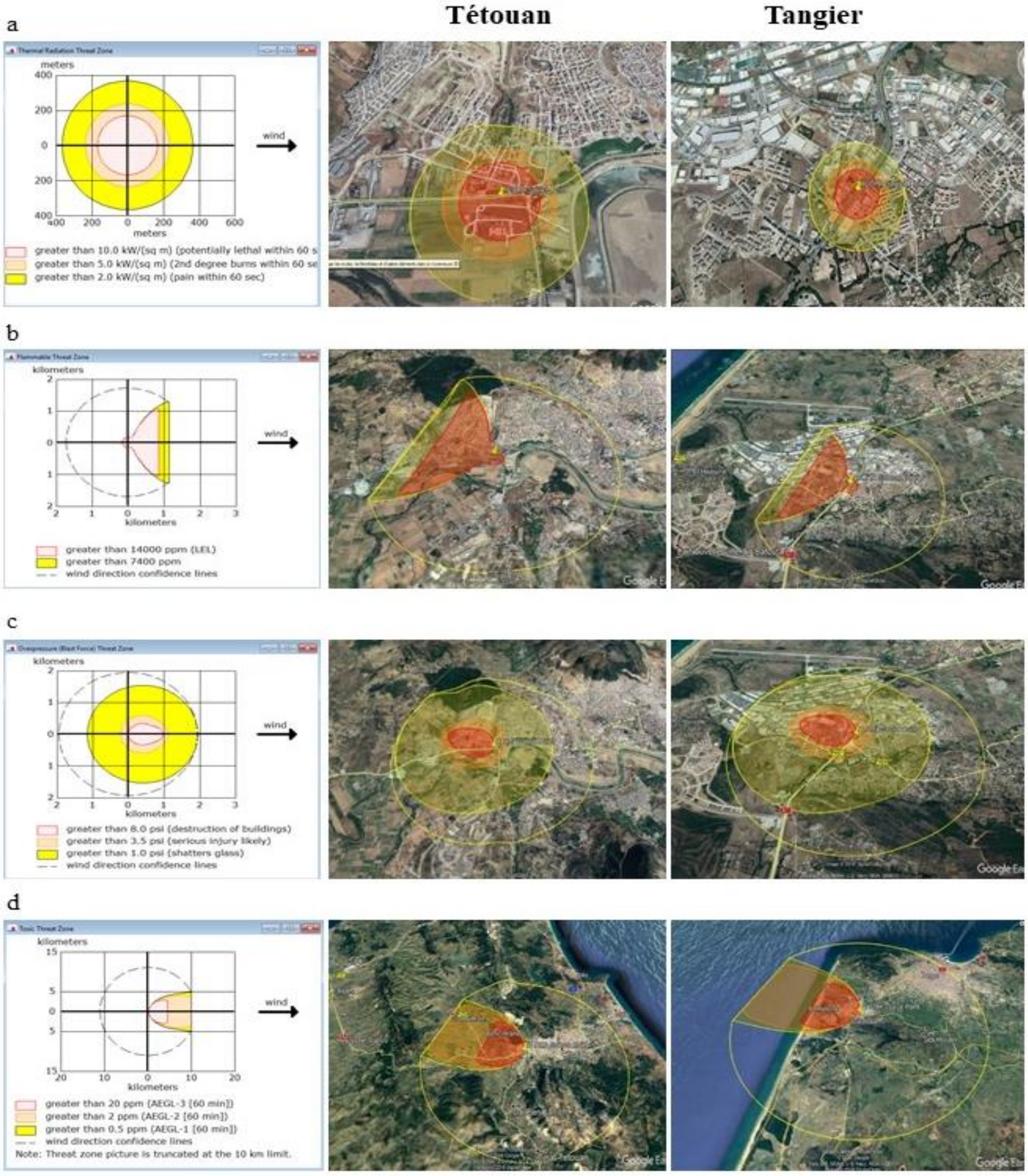
CLASS Of DATA	TYPE OF DATA	VALUES		
SITE DATA	Location:	TANGIER, MOROCCO		
	Building Air Exchanges Per Hour:	0.50 (enclosed office)		
	Time:	January 24, 2017 1258 hours ST (user specified)		
CHEMICAL DATA	Chemical Name:	**Gasoline**	**Butane**	**Chlorine**
	ERPG-1 / AEGL-1	200 ppm	5500 ppm	0.5 ppm
	ERPG -2 / AEGL-2	1000 ppm	17000 ppm	2 ppm
	ERPG -3 / AEGL-3	4000 ppm	53000 ppm	20 ppm
	IDLH	5 mg/m3		10 ppm
	LEL	14000 ppm	16000 ppm	
	UEL	74000 ppm	84000 ppm	
	Ambient Boiling Point:	125.4 ° C	-0.6° C	-34.1° C
ATMOSFERIC DATA (Manual Input of Data)	Wind / Stability	Scenario I: 1.5 m/s (from EST) / (F: Moderately stable conditions)		
		Scenario II: 14 m/s (from EST) / (D: Neutral conditions)		
	Ground Roughness:	urban or forest		
	Cloud Cover:	5 tenths		
	Air Temperature (C)	Scenario I: Average minimum temperature: 13		
		Scenario II: Average minimum temperature: 21		
	Relative Humidity:	70%		
SOURCE STRENGTH	Description:	Tank contains liquid Leak from hole in horizontal cylindrical tank Flammable chemical escaping from tank (not burning)		
	Tank Volume:	Tank is 95% full		

Accident scenarios, involving the inventoried hazardous substances, are carried out in order to estimate the impact on the surrounding population of such events. Three types of accidental events are considered because of their impacts on planning and emergency response:

- toxic clouds;
- fires;
- explosions.

Different scenarios have been simulated in ALOHA considering small, medium, and large spill size with two different weather atmospheric conditions (F and D) and for two kinds of wind speed (1,5 and 14 m/sec). In the figure below , a pool fire scenario with large spill size located in Tangier appears.

Given the assumption that gasoline has been transported by truck on road, also the Shortcut method has been applied. Shortcut method classifies gasoline as flammable liquid and it provides directly the relative table containing the hazard radius. Those values represent the hazard distances for each scenario outcome case computed considering two different weather atmospheric conditions (F2 and D5) and four different thresholds of lethality.



a: Pool fire scenario with large spill size
b: Flash fire scenario with large size
c: UVCE scenario with large size
d: Toxic scenario with large size (Chlorine)

Figure 37: hazard zones for the different scenarios computed by Aloha

Table 32, 33, 34 and 35, shows the hazard radii obtained applying the two methodologies for the same scenario at the same conditions.

The values obtained differ little from one another and this fact assures the reliability of the proposed speditive method. The distances computed by Shortcut Method has been used to apply QRA and compute societal risk for the proposed logistic operation of the case study.

Table 32: Radius of hazard zone computed by Aloha and Shortcut expressed in meters

Pool Fire			
Scenario (Release Size)	**Stability / Wind Speed**	**Distance (meters) By ALOHA**	**Distance (meters) By Shortcut Method**
small	F: 1.5m/s	77	100
small	D: 14m/s	92	105
medium	F: 1.5m/s	134	130
medium	D: 14m/s	150	130
large	F: 1.5m/s	164	145
large	D: 14m/s	181	150

Table 33: Distance from the source of release for Flash fire & UVCE scenarios for Gasoline computed by Aloha expressed in meters.

Scenario (Release Size)	**Stability / Wind Speed**	**Distance from the source of release (in the wind direction) (meters)**	
		Flash Fire	**UVCE**
small	F: 1.5m/s	358	404
small	D: 14m/s	103	127
medium	F: 1.5m/s	721	823
medium	D: 14m/s	171	208
large	F: 1.5m/s	860	975
large	D: 14m/s	241	285

Table 34: Distance from the source of release for Flash fire & UVCE scenarios for Butane computed by Aloha and Shortcut expressed in meters.

Scenario (Release Size)	Stability / Wind Speed	Distance from the source of release (in the wind direction) (meters) BUTANE		Distance (meters) By Shortcut Method	
		Flash Fire	UVCE	Flash Fire	UVCE
small	F: 1.5m/s	383	420	250	150
small	D: 14m/s	125	137	170	105
medium	F: 1.5m/s	457	506	330	190
medium	D: 14m/s	142	170	200	140
large	F: 1.5m/s	457	506	430	250
large	D: 14m/s	142	170	260	170

Table 35: Toxic Area of vapor cloud for Chlorine computed by Aloha and Shortcut expressed in meters.

Toxic Area of Vapor Cloud			
Scenario (Release Size)	**Stability / Wind Speed**	**Distance (meters) By ALOHA**	**Distance (meters) By Shortcut Method**
small	F: 1.5m/s	2000	2000
small	D: 14m/s	684	960
medium	F: 1.5m/s	4000	2000
medium	D: 14m/s	3600	4500
large	F: 1.5m/s	4500	2000
large	D: 14m/s	5500	4500

III.2. QRA application

The societal risk has been computed for the two alternative proposed paths.

To finalize the QRA application the following data has been used. A conditional probability value CRP =0.1 is take into account; small, medium and large spill size probability is set respectively as SSD =0.5, 0.3 and 0.2. The two meteorological condition D and F appear with the same probability PWS=0.5.

In order to estimate societal risk, it has been assumed that only a part of persons exposed in the impact area is effectively affected by the event (i.e exposures/100 (CCPS, 2008)).

Based on the above assumptions, the FN curves have been calculated for the two paths, figure 38 and 39 show an example of results obtained for the transport of gasoline (the other scenarios are in appendix 1) . FN curve expresses the relationship between the annual accident probability F and the risk loss expressed as number N of fatalities

The graph shows, as dotted lines, the limit curves of the ALARP zone, according to (DNV, 2014). The upper line (ALARP 1 line in the graph) is tolerability line, while the risks above this line is regarded as intolerable. The bottom line (ALARP 2 line in the graph) is the negligible risk line and risks below it can be considered as negligible.

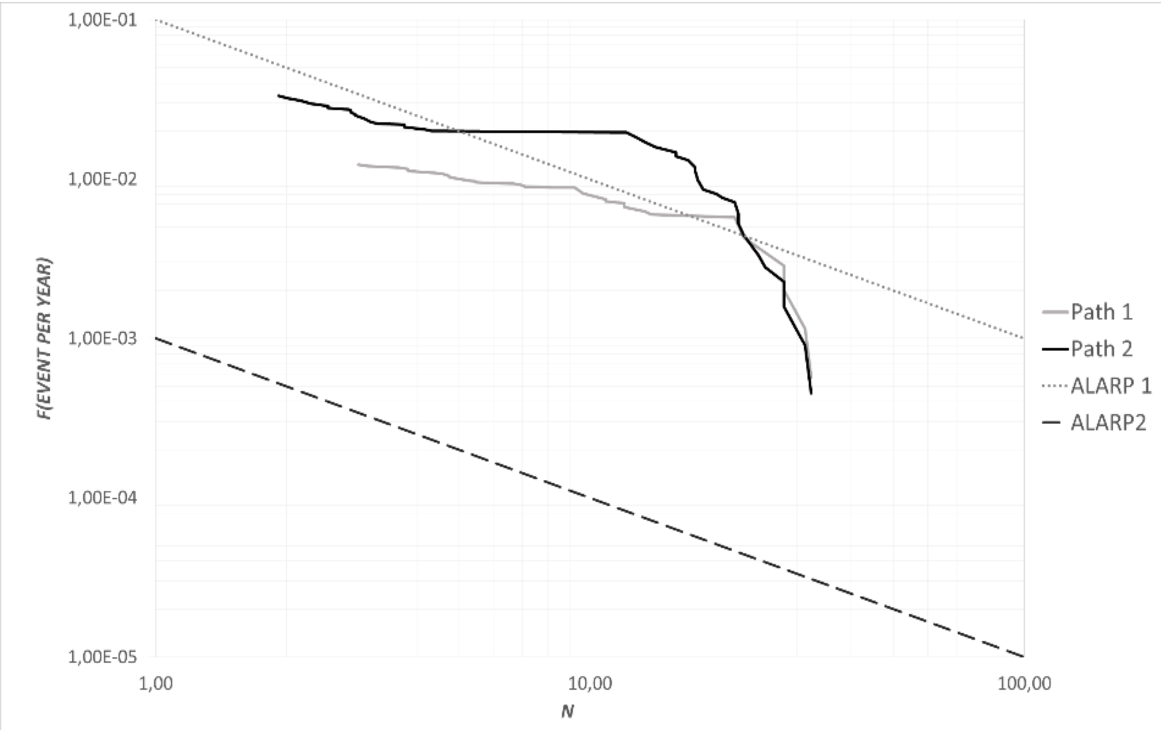


Figure 38: Pool fire scenario with large spill size of Gasoline located in the Tangier

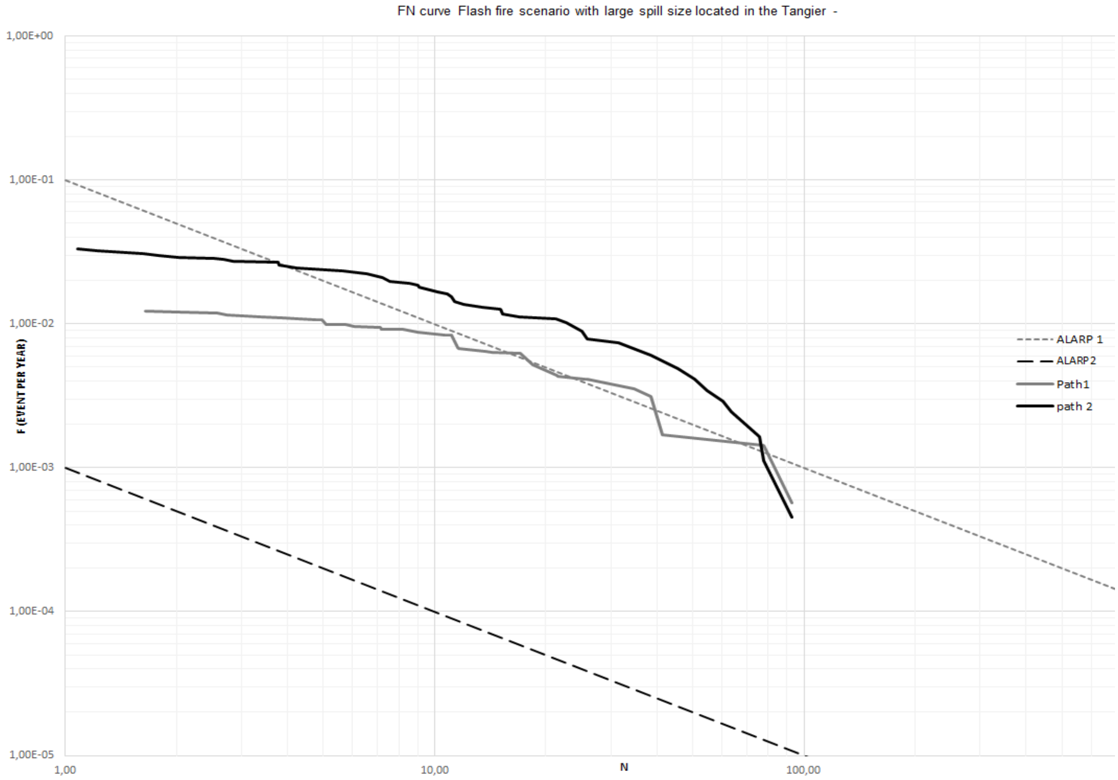


Figure 39: Flash fire scenario with large spill size of Gasoline located in the Tangier.

It can be noticed that for the two different selected paths, the results obtained are relatively different. Concerned Tangier case study, The Path 1 is quite contained in the ALARP zone while the Path 2 has a part which can be regarded intolerable. This latter alternative strategy is not favorable in term of risk.

On the other hand, in the case of transport of these dangerous materials to the city of Tetouan we show tha thet two routes contined in the ALARP zone , with a little danger of road used (path 1) as the alternative path 2.

The following two figures show a map of the degree of danger obtained for each segment for two cases study.

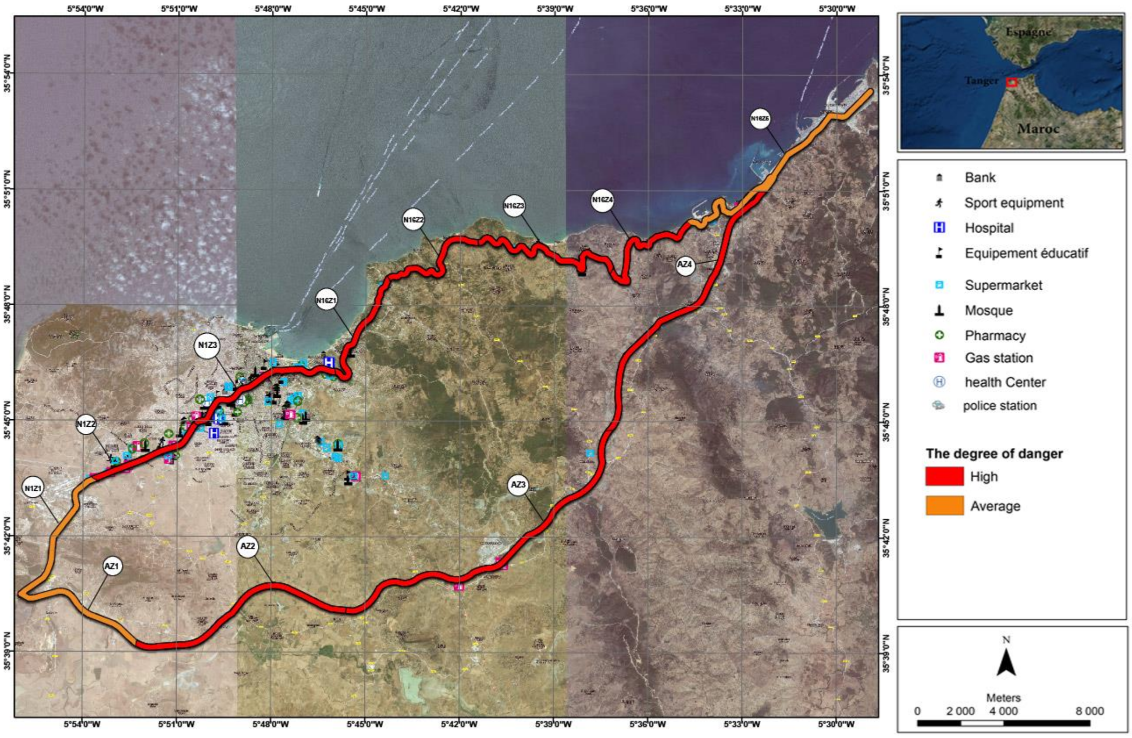


Figure 40: risk mapping according to its degree of danger for each segment of the road network (MAPT – Tangier)

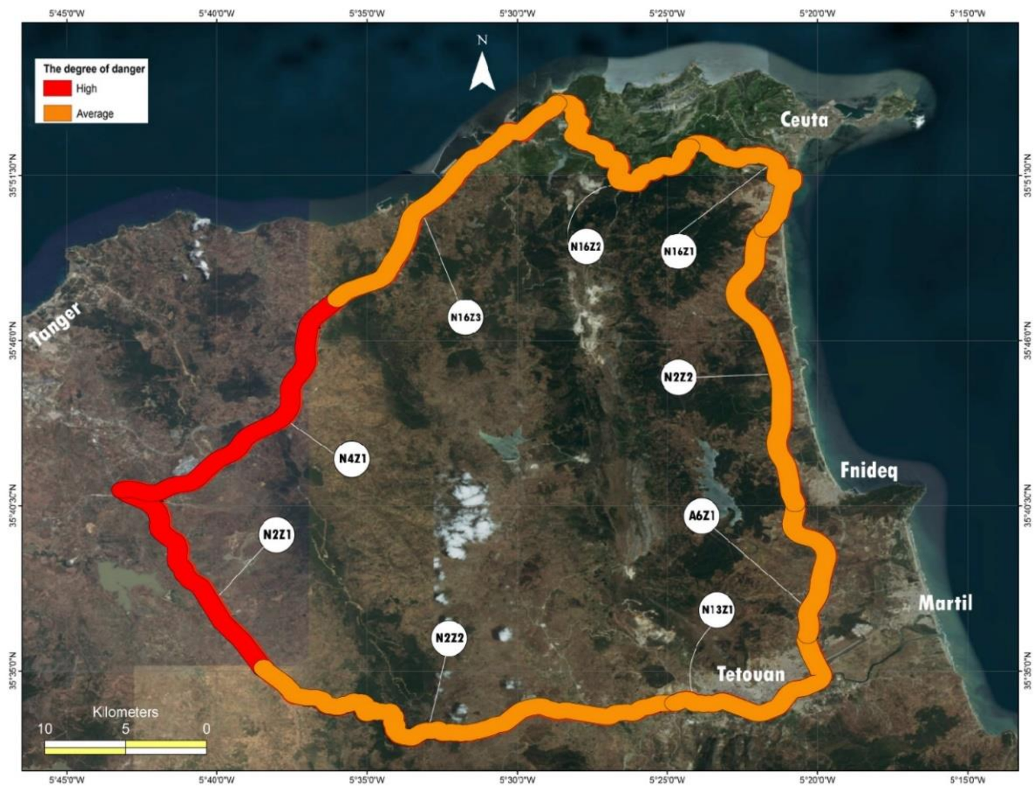


Figure 41: risk mapping according to its degree of danger for each segment of the road network (MAPT - Tétouan).

Conclusion

The proposed approach could improve the hazmat road transport safety minimizing the population exposure by optimizing the scheduling of hazmat vehicle shipments in the planning phase. Hazmat operators could apply this methodology to define the routes at minimum risk. On the other hand, the possibility to evaluate FN curves according to risk acceptance criteria might provide basis for decisions on the implementation of risk-reducing measures.

In the industrial context, the utility of the adoption of QRA decision tool for risk management is often underestimated. QRA could provide informed assessment of cost risk exposures with special relevance in the hazmat transportation context. Besides, it is able to offer significant data to define mitigation risk strategies.

Due to the SoS nature of the hazmat transportation problem, the large amount of data and information required to perform the QRA have to be collected from the different subjects involved in these activities. Those constraints represent an open issue also due to the fact that hazmat traffic information is considered sensible data in terms of safety and security. The use of the proposed basic approach allows the user to carry out a speed QRA obtaining still significant risk values. In a real-time or operational decisional level framework, reliable data about risk, even if approximated, could be very suitable to identify immediately the value of risk for a hazmat accidental event.

Anyway, at tactical and strategical decisional level, QRA for hazmat transport deserves to be analysed with more detailed multi-criteria models, enabling a deeper analysis of the problem.

Chapter IV: Maritime risk analysis. Case Study: Strait of Gibraltar - Mediterranean Sea

Partially reproduced from:

- Soussi et al,. "An Oil Spill Trajectory Model: Validation in the Mediterranean Sea." IEEE ISSE 2019, 5th IEEE Iternational Symposium on System Engineering, 2019. DOI: 10.1109/ISSE46696.2019.8984542

- Soussi et al,. "A Lagrangian-based oil spill model and a coastal risk assessment in the Mediterranean Sea". … *(to be submitted).*

Introduction

In case of an oil spill incident in the marine environment, it is mandatory to know the trajectory of the pollutant slicks, so as to organize the oil recovery operations and to protect the areas exposed to the risk of pollution.

The development of oil spill drift models in inland waters and in the sea is based on the frequency of pollution incidents and to the harmful impact of these incidents on the environment.

A Lagrangian model has been proposed to identify risk areas that could be affected in the occurrence of a spill incident. The proposed model was applied to the real case occurred in the Mediterranean Sea toward the French coast in in October 07, 2018, and the results have confirmed the reliability and relevance of the proposed model. The choice of the physical phenomena which should be taken into account in the modelling of oil slick drift in marine waters is conditioned, in the first place, by the realization of a detailed state of art.

The oil spill is one of the most dangerous sources of pollution that threatens maritime safety because of its serious consequences especially in the Mediterranean where, are listed more than 100 million gallons of crude oil spilled annually (Hosein et al., 2019; Cláudio et al., 2014). Statistically, 52 % of total oil spills in the Mediterranean come from shipping, compared to 48 % for other seas (Albakjaji, 2011).

Generally speaking, maritime oil transport is safer than other types of goods transport. The storage tanks used in the transportation black products (fuel oil, tars), which are the most polluting products, often lack regular maintenance and structural quality (Le Couviour, 2008). White Petroleum Products (WPP) (i.e. gas oil, gasoline, kerosene, naphtha) are rather more dangerous because of their flammability, yet less polluting due to their volatility.

Oil spills conduce the degradation of the marine flora and fauna (Witchaya et al., 2017; Al-Majed et al., 2012; A.Vega et al., 2009; Ventikos et al., 2004). Moreover, oil spills decrease sun lighting and air in the seawater. Consequently, tiny plants and animals that form the plankton disappear affecting the overall food chain.

A released petroleum product is subjected to the effects of the environment which generates its dispersion in the marine environment and, simultaneously, it modifies its physical and chemical characteristics, the so-called "weathering” of the oil (Mishra et al., 2015). The behavior of oil drift at sea is the result of a set of interactions that occur between the spilled product and the external environment conditions. When hydrocarbons are discharged at sea, they suffer a large number of transformation processes: drift and spreading, evaporation, dissolution, dispersion, emulsification, photo-oxidation, biodegradation, sedimentation, pouring, stranding and interaction with sea ice. While some processes are currently well-understood, such as spreading and evaporation, others remain poorly known (photooxidation and biodegradation).

In this study, a maritime risk model based on the 2D Lagrangian model has been developed and validated. The proposed oil spill model considers the spreading effect, advection and diffusion processes. The purpose of the proposed paper is twofold. Firstly, it aims at defining a simple methodology to classify the risk in marine and coastal area due to maritime hazardous material transportation. Secondly, the proposed approach provides a useful tool which can support the spill response teams and other operators in facilitating oil spill planning and preparedness.

The following section of the chapter represents a review of the main shipping accidents accompanied by the massive oil spills in the Mediterranean Sea. The third part introduces the proposed Oil Spill Model. In the section 4, the application of the proposed model is described in the context of a potential maritime accident in the Strait of Gibraltar in the Mediterranean Sea.

I. Some data on maritime traffic

Worldwide shipping traffic can be summarized in some key elements. Hydrocarbons transported by sea represent an annual figure of between 1200 and 1500 million tons (Mt) for crude oils and between 200 and 350 million tons (Mt) for refined products (gasoline, domestic fuels, heavy fuels, bitumen), transported by a fleet of about 6,500 ships (Marchand, 2003).

I.1. Insights on the Mediterranean

The Mediterranean Sea is a semi-closed warm and salty sea. The renewal of its superficial water mass is done completely only by the Strait of Gibraltar in 70 to 100 years (Albakjaji, 2011), only the 13 kilometers of the Strait of Gibraltar that separates it from the Atlantic Ocean. That's why the Mediterranean has a low tidal range and undergoes greater evaporation (3130 km^3/an (Carré, 1977)) and thus records higher salinity levels.

I.2. The characteristics of maritime transport in the Mediterranean

The Mediterranean Sea is a very important transit area for transporting various goods and especially petroleum products. According to the estimates of Malta's Regional Center for Emergency Response to Accidental Marine Pollution (REMPEC), more than 400 million tons annually are transported for more than nine thousand trips in the Mediterranean Sea, and represent approximately 20 % of world traffic, between 250 and 300 tankers crossing the sea every day (REMPEC, 2018).

The Mediterranean Sea represents 0.7 % of the surface of the water and receives 17 % of the world marine pollution by hydrocarbons. It is estimated that between 100,000 and 150,000 tons of crude oil are thrown into the sea each year by shipping activities (Greenpeace International, 2010).

Accidental oil spills occur frequently with an average of 60 spills per a year in the Mediterranean, 15 of which involve ships that spill oil and chemicals. They can occur at any time in any part of the Mediterranean (European Environment Agency, 1999).

I.3. Sources of oil pollution in the Mediterranean Sea

Oil pollution related to maritime transport activities in the Mediterranean Sea has two main origins (operational pollution, accidental pollution).

- ❖ **Accidental Pollution** may result in the loss of cargo or fuels as a result of grounding, collision and minor accidents occurring on board the ship, thus accidental pollution is random.
- ❖ **Operational pollution** results from the discharge of ship-generated wastes such as garbage, sewage, dirty bilge water, and tank cleaning water as well as engine exhaust and tank ventilation emissions.

Accidental pollution, illustrated by massive oil pollution, is however less important in quantity than operational pollution. Oil spills caused by accidents account for at least 30 % of this pollution, compared with 70 % for operational pollution (Albakjaji, 2011).

Accidental spills attract the attention of the public, the media and politicians, while operational pollution does not have this character, this is due to a lack of information on its frequency and its harmful effects on the environment marine. In addition, accidental pollution appears to be more irritating than any other categories of marine oil pollution, probably because of their concentrated nature. Large quantities of oil released on a limited marine surface for a short period of time.

I.4. Historical spill accidents

The major accidents oil spill occurred in the world can be summarized in the following table:

Table 36: The major accidents oil spill occurred in the world according to chronological order

Spill / Vessel	Dates	Description
Torrey Canyon	18March 1962	Grounding of a tanker in charge near the English Cornish coast: the first massive oil spill (119,000 tons) in the history of shipping, and the first oil spill affecting two countries (the United Kingdom and France).
Amoco Cadiz	16 March 1978	Grounding of a tanker in charge on the Breton coast (the largest spill at the coast (227,000 tons of crude oil in 15 days) of the history of maritime transport).
Atlantic Empress	19July 1979	Collision and fire of two tankers in charge of crude oil (500,000 tons) off Trinidad: a larger oil spill (280,000 tons of crude oil, partly burned).
Tanio	7 March 1980	Breakdown of a tanker in charge (26,000 tons of crude oil), causing a small spill (6,000 tons), but in an area affected two years earlier by an exceptional spill (Amoco Cadiz) with a relief of a part of submerged wreck.
Exxon Valdez	24 March 1989	Grounding of a tanker in charge (180,000 tons of crude oil) in Alaska, causing à medium-sized spill (40,000 tons).
Kharg-5	19 December 1989	explosion of an Iranian oil tanker carrying 284,000 tons of crude oil and drifting along the Moroccan coast, between Safi and Larache, leaving slicks of water hydrocarbons at a rate of 200 tons per hour.
Haven	11 April 1991	Fire and explosion of a tanker in charge (144,000 tons of crude oil), at anchor in front of Genoa.

Aegean Sea	3 December 1992	Grounding of a tanker in charge at the entrance of the Port of Corunna, Spain: an average spill (80,000 tons of crude oil, combustion of the part), but in a zone of very strong fisheries exploitation.
Braer	5 January 1993	Stranding of a tanker in charge on a rocky coast of the Shetland Islands: on average spill (84,500 tons of crude oil) in exceptionally bad weather conditions.
Sea Empress	15 February1996	Grounding of a tanker in charge (130,000 tons of crude oil) at the entrance to Milford Haven Bay, Wales: an average spill (73,000 tons), subject of a dispersant treatment of a dimension never before seen.
Katja	7 August 1997	The pollution of the oil tanker Katja in the Port of Le Havre illustrates an essential fact: an accidental spill of hydrocarbons, altogether modest, compared to major accidents. The quantity transported: 80,000 tons, the quantity dumped 187m^3. The factor leading to the accident is the damage.
Erika,	12 December1999	Breakdown of a tanker in charge (31,000 tons of heavy fuel oil) off Brittany: the first large spill of heavy fuel oil (20,000 tons) and a relief of submerged wreck (11,000 tons)
Prestige	13 November 2002	Breakdown of a tanker in charge (77,000 tons of heavy fuel oil) off Galicia: a heavy fuel oil spill (estimated at 64,000 tons), the European record for the length of affected coastline (more than 3,000km) and unprecedented wreck relief (13,000 tons recoveree more than 3,800 m of background).

II. State of art in the Mediterranean Sea

The Mediterranean Sea is a tragic theater of maritime accidents. In 1991, the Haven disaster in the coastal area of Genoa in Italy, which produced the release of 144,000 tons of hydrocarbons, has been ranked as the fourth dangerous event among global shipping accidents (P Guidetti et al., 2000). In addition, the Mediterranean is threatened by accidents occurring outside its geographical area. For example, the maritime accident that occurred in the Atlantic Ocean as a result of a collision between the oil tanker «Seat Spirit», which was carrying heavy oil, and «Hesperus», which transported chemical products, caused a spill of 12,200 tons of oil. However, depending on weather conditions (wind speed and ocean currents), the contaminants were transferred by the Strait of Gibraltar to the Moroccan, Spanish and Algerian coasts (LAOTBOZZI, 2009)

According to recent statistics from the "Alerts and Accidents database" (REMPEC, 2018), containing data on spills (quantity, type of spilled oil, location and on the ships involved) and accidents likely to cause oil spills in Mediterranean Sea. 979 marine accidents occurred between 1977 and 2017. These accidents cause various spills (petroleum products, chemicals... etc.). About 497,117 tons of oil were dumped into the Mediterranean Sea as a result of accidents.

In relation to oil spills, 268 tankers are involved in maritime accidents in the Mediterranean Sea in the same period (90 accidents for "Volatile Oil" and 178 for "non-Volatile oil"), as shown in the following table:

Table 37: Number of oil spill accidents in the Mediterranean Sea between 1977 and 2017

years	**Number of accidents**	**Type of pollutant**	
		Volatile Oil	**Non-volatile Oil**
Between 1977 and 1987	46	3	43
Between 1988 and 1997	73	5	68
Between 1998 and 2007	28	3	25
Between 2008 and 2017	121	79	42

According to these statistics, we note that the number of accidents involving accidental spills decreased between 1998 and 2007, with 46 and 28 accidents occurred respectively. This decrease can be attributed to the implementation of international, regional and national legislations and particularly at the level of European countries (the key Points). The European Union has put in place a series of strict measures (Erika I and Erika II... etc.) to control ships entering European ports. Also, the application of modern methods safer in the shipbuilding industry (Albakjaji, 2011). But despite this, we notice that between the years 2008 and 2017 the number of accidents to increases again especially in Greece which represents 112 accidents of spill on 121 accidents in the Mediterranean.

Greece holds the record for oil spilled in the main incidents, with 378,027 tons, followed immediately by Italy with almost 364,823 tons and Spain with 333,492 tons (REMPEC, 2018)

It should be noted that incidents occurring in the European parts are more frequent than in other parts of the Mediterranean, statically speaking 232 incidents in European Mediterranean countries out of 268 incidents in all the Mediterranean (Table 38). This Increase in the European part is due to the concentration of the petrochemical industries, (in Italy alone, there are 14 oil ports and 17 refineries) (Albakjaji, 2011). Without forgetting the increase in trade between European countries because European integration and economic development measures of these countries, (traffic between EU countries which is essentially bulk traffic). The impact appears also in the proximity-related intensity of densities between Gibraltar and Spain on the one hand, and between Sicily and Italy on the other. The relatively high density between Gibraltar and Sicily reflects the importance of the Western Mediterranean as a transit zone (Roux et al., 2004).

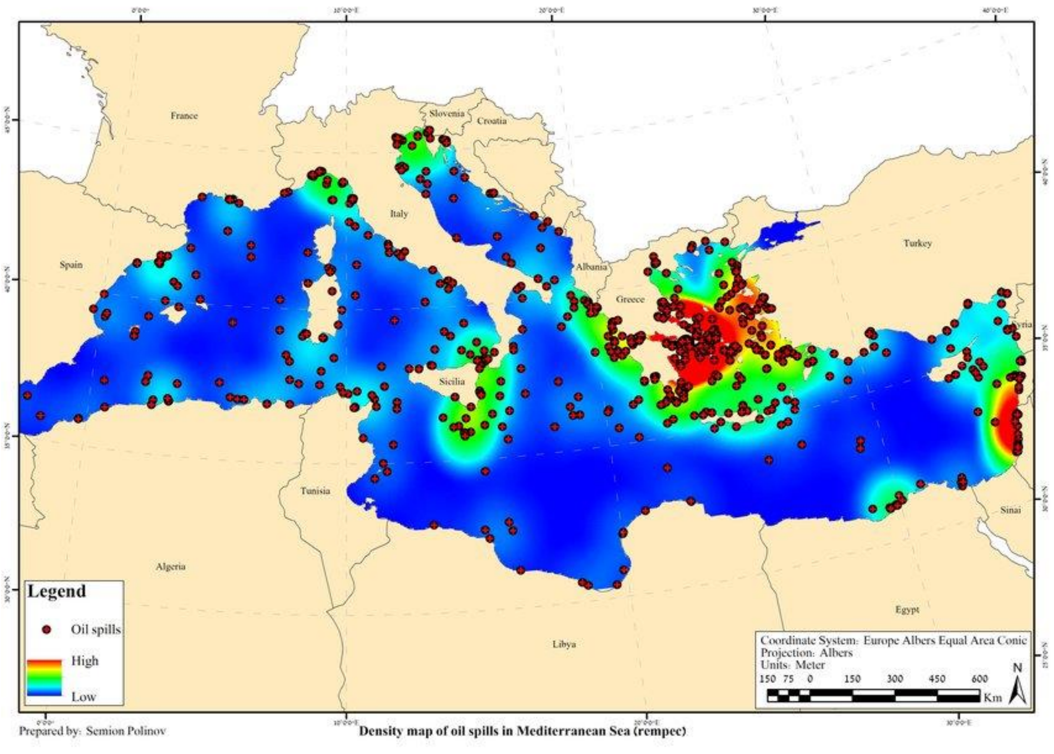


Figure 42:distribution of oil spills in Mediterranean Sea 1977-2017
(Source: REMPEC, S. Polinov)

Table 38: The main oil spill accidents in the Mediterranean for the period 1977 - 2017

Location of the accident	Numbers of accident	Cause of the accident										Quantity spilled (tons)			Type of pollutant	
		Engine or machinery failure	shipwreck	Leaking oil or gas	Fire or explosion	grounding	Cargo Transfer Failure	Structural failure of the installation	Contact	Collision	other	<7	7<x<700	>700	Volatile Oil	Non-volatile Oil
Algeria	5		1			1	1				2	2	2	1		5
Croatia	5						5					1	4			5
Cyprus	7		2				2				3	4	3			7
Egypt	5						3			1	1	1	4			5
France	3						1			2			2	1		3
Greece	161	1	36	49	1	19	5	8		10	32	71	74	16	81	80
Israel	13		3			1	1			2	6	6	7		2	11
Italy	39			1		4	12		1	10	11	22	12	5	3	36
Lebanon	5						1		1		3	2	2	1	2	3
Libya	1					1						1				1
Malta	5					2	1				2	3	2			5
Montenegro	2										2		2		1	1
Spain	10		1			1	1			1	6	4	4	2	1	9
Syria	1						1						1			1
Tunisia	2					1	1					1	1			2
Turkey	4					3					1	3	1			4
Total	268	1	43	50	1	33	35	8	2	26	69	121	121	26	90	178

Source: REMPEC database (accessed 18 September 2018)

II.1. Statistics on spilled quantities

For historical reasons, oil spills generally classified by size (<7 tons between, 7-700 tons and >700 tons), although the actual amount spilled is also recorded. Now the information is available in several databases as REMPEC or ITOPF, nearly 10,000 incidents, the vast majority (84%) belong to the smallest category, i.e. <7 tons (ITOPF, 2006).

It should be noted that figures for the amount of oil spilled in an incident include all oil lost to the environment, including that which is burned or remains in a sunken vessel. There is considerable annual variation in both the impact of oil spills and the amount of oil lost.

The incidence of major spills is relatively low and a detailed statistical analysis is rarely possible; therefore, the focus is on identifying trends. For example, the table below shows that the number of large spills (> 700 tons) has decreased significantly over the last 20 years. The average number of large spills per year during the 2000s was less than one-third of that observed during the 1980s. It should be noted that all 10 spills between 2008 and 2017 occurred in Greece.

Table 39: Number of spills and quantities by years in the Mediterranean, between 1977 and 2017

Quantity spilled (tons)		**years**			
		Between 1977 and 1987	**Between 1988 and 1997**	**Between 1998 and 2007**	**Between 2008 and 2017**
<7	Number of spill accidents	20	36	17	48
	Total Quantity (tons)	31	57	18	105
7<x<700	Number of spill accidents	18	31	9	63
	Total Quantity (T)	2595	5150	1835	9378
>700	Number of spill accidents	8	6	2	10
	Total Quantity (T)	283170	151700	3000	74700

Source: REMPEC database

Most incidents result from a combination of actions and circumstances, all of which contribute to varying degrees to the end result. The following analysis explores the impact of spills of different sizes in terms of primary event or ongoing operation at the time of the spill. These "causes" have been grouped into "Operational" and "Accidental". Spills for which relevant information is not available or for which the cause is not one of those listed are listed under "Other".

Table 40: Number of incidences of spills by accident size in the Mediterranean, between 1977 and 2017

Type of spill	Quantity spilled (tons)			Total
	<7	7<x<700	>700	
operational				
Loading / unloading	17	16	2	35
Leaking oil or gas	10	36	4	50
Other operations	2	1		3
accidental				
Collision	8	13	5	26
grounding	21	8	4	33
Structural failure of the installation	3	5		8
Fire or explosion	0	0	1	1
shipwreck	22	17	4	43
Other	38	25	6	69

From the table 40, we will notice that:

- Most spills of tankers in the Mediterranean Sea are the result of accidental causes such as stranding, collisions and shipwrecks, which generally result in much larger spills;
- most tanker spills result from routine operations such as loading, unloading and bunkering that normally occur at ports or oil terminals;
- the majority of these spills are small to medium-sized, approximately 53% of the incidents for quantities between 7 and 700 tons.

The following figures (43 and 44) represent percentages of different causes of spills in the Mediterranean Sea depends on the spill size for the period between 1977 and 2017.

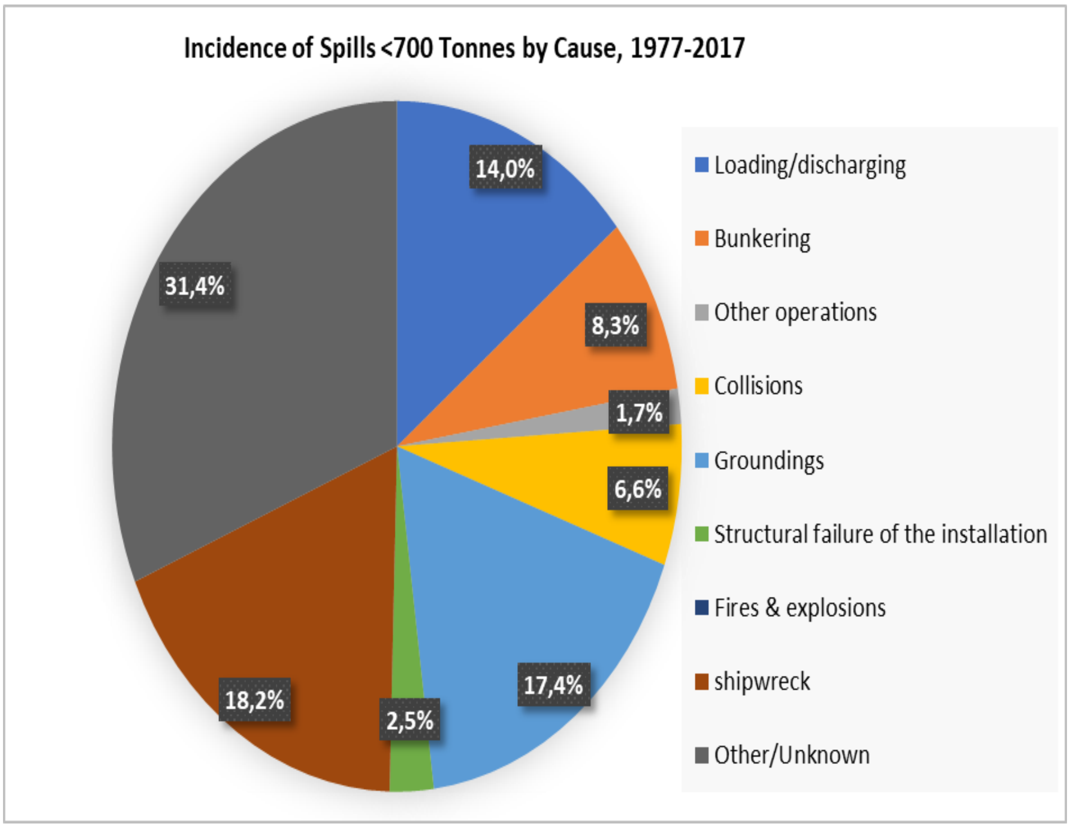


Figure 43: incidence of spills <700 tons by cause, 1977-2017

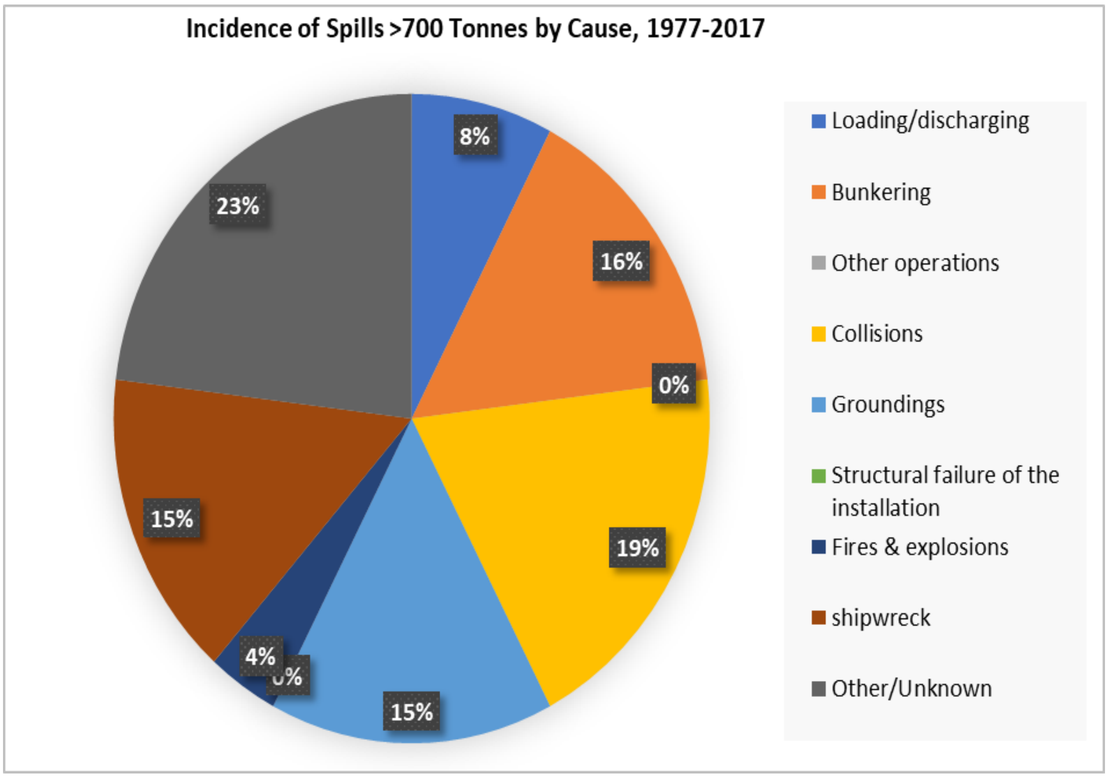


Figure 44: incidence of spills >700 tons by cause, 1977-2017

We can therefore summarize all the incidents of spills in the Mediterranean between 1977 and 2017 in the following graph.

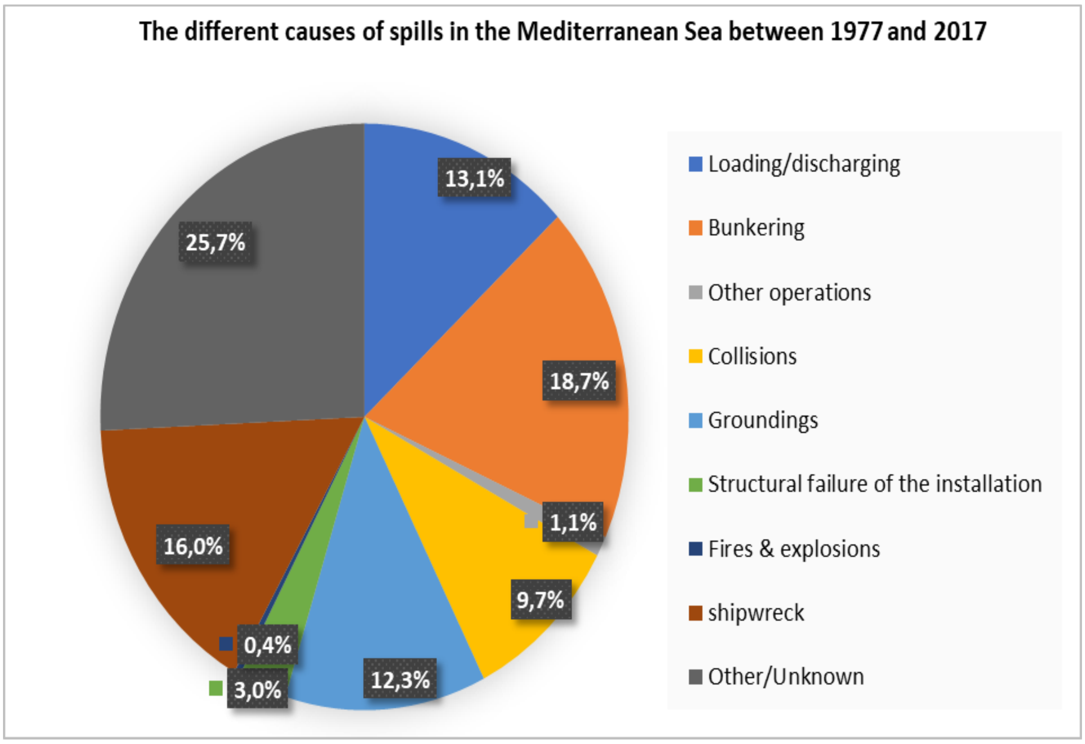


Figure 45: The different causes of spills in the Mediterranean Sea between 1977 and 2017.

III. Hydrocarbon weathering process

The behavior of hydrocarbons at sea depends strongly on the nature of the spilled products. Then must also be account the area of the spill (coastal zone, estuary, offshore) and the weather-ocean conditions (tide, currents, wind, agitation of the sea, sunshine).

A petroleum product is subjected to the effects of the environment which causes the dispersion in the marine environment and at the same time modifies their physical state and their chemical characteristics; what is called the weathering of oil. None accident is precisely the same; the behavior of hydrocarbons released at sea is the result of a set of interactions that exists between the spilled product and the external environment.

Remind us that the crude oils are complex mixture and variable of hydrocarbons; that’s why their consistency may be from a volatile liquid to that of a viscous semi-solid. The refined products represent different distillation fractions of crude oils in the ascending order by their density: gasolines, kerosene, fuels, lubricating oils, residual fuels, bitumen; also, a petroleum product is characterized by a chemical composition and its physical properties.

There are two categories of hydrocarbons; the aliphatic hydrocarbons which are composed of linear open chain (n-alkanes), or cyclical (Naphthenes) with five or six carbon atoms (cyclopentane or cyclohexane) with polycyclic combinations. Aromatic hydrocarbons are consisted of an aromatic nucleus (benzene derivatives) or more aromatic nuclei (poly-aromatic hydrocarbons) (Doerffer, 1992).

In general, aromatic hydrocarbons are the main cause of the eco-toxicological impact of oil pollution on aquatic ecosystems. Resins and asphaltenes represent heterocyclic molecules (N, S, O) with high molecular weight. This fraction also contains metals such as nickel and vanadium. The effects on aquatic fauna and flora are not clearly known and the assessment of such polymers is almost totally excluded from chemical analysis (Marchand, 2003).

The most important physical properties that affect the behavior of a petroleum product discharged into the marine environment are:

- ***Density:*** hydrocarbons almost always have a density below 1, which allows them to float (normalized value between 800–1000 kg/m3) (Speight, 2006). However, as a result of aging phenomena (evaporation & emulsification), the density gradually increases to values close to those of water, making their buoyancy more uncertain;
- The distillation characteristics, which have a *flash point* that represents the temperature from which a heated product will give off flammable vapors;
- ***The pour point*** is the temperature at which it stops flowing;
- ***The viscosity*** represents the flow resistance, high viscosity hydrocarbons flow less easily than those with lower viscosity.

The viscosity of the spilled oil influences the rate of spill spread, the adhesion capacities of the oil, its penetration into soil and beach sediments and the ability of pumps used in a cleaning operation to remove oil from the surface (Doerffer, 1992).

The transport of a slick of oil is generally induced by the current, the wind, the waves and the turbulent diffusion. Wind and currents are the two major processes that constitute the phenomenon of convection in the marine environment (ASCE, 1996; Jordi et al., 2006; Carracedo et al., 2006; Guo, 2009; Cheng et al., 2011). There are two types of convection: convection at the surface of the water level, which a slick "floating» is related to wind friction and surface current (an oil slick moves in a direction and speed equal to around 3% of the vector sum and about 100% of the wind speed of the velocity of the current (Reed et al., 1999; Chao et al., 2001; McCay, 2004; Guo et al., 2009; Periáñez et al., 2010).

The second run in the water column and causes hydrocarbon particles with suspended or dissolved. However, of the convection, the turbulence generated by wave overwash and the shear forces exerted by the coasts and sea floor had an effect the break up the slicks surface and spread it horizontally and vertically.

The most physicochemical processes resulting the change in physical properties of the hydrocarbon discharged at sea over time (figure 46).

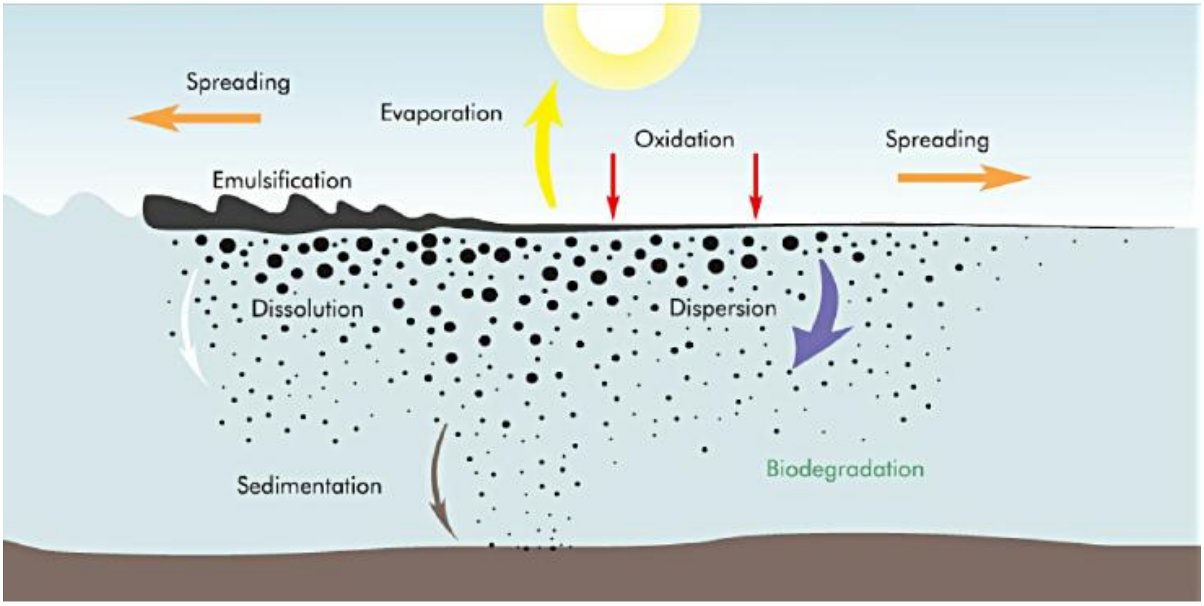


Figure 46: Weathering process of oil spill
(Source: ITOPF, 2013)

In general, there are two distinct phases during processes an active and predominant part:

III.1. Short-term evolution phase

Intervenes in the first days and following the spill marked by the following processes:

III.1.1. Spreading of the slick

Spreading is one of the most important processes, not only for predicting the extent of pollution, but also because it conditions other processes of slick transformation. Indeed, spreading grows the exchange surfaces and increases the mass transfer by evaporation and dissolution. Table 41 represent the three phases of hydrocarbon spreading after spillage over time (Fay, 1971).

Table 41: Phases of hydrocarbon spreading after spillage over time

Phase	Driving force	Resistive force
1	Gravity	Inertia
2	Gravity	Viscosity
3	Surface tension	Viscosity

The spread of a slick involves the forces below (Goeury, 2012):

- **Gravitational forces**: gravity forces;
- **Surface tension forces**: surface tensions at the water-air interfaces, hydrocarbon-air, water-hydrocarbon;
- **Viscosity forces:** viscous friction at the water-oil interface.

III.1.2. The evaporation of the light fractions

Evaporation is the most important transformation process in mass transfer during the first two days for the evolution of the spill. It varies according to the nature of the hydrocarbon, where it can evaporate completely in the case of a gasoline or a diesel fuel, in the order of 40 to 50% in the case of a light crude oil and approximately 10 to 15% in the case of a heavy fuel oil (Bocard, 2006).

Evaporation is influenced by the nature of the hydrocarbon (density, viscosity), the temperature of the sea water, the wind speed and the slick surface due to spreading.

III.1.3. The dissolution of the most soluble compounds

Generally, it is estimated that a very small part of the hydrocarbon mass will dissolve in the water. However, the most soluble compounds are often the most toxic, although the dissolution in very small quantities of these substances can have a very strong ecological impact.

The physical process of dissolution is well known but the description of a hydrocarbon spill is complex because of the numbers of components constituting in the product. And it’s a priori necessary to know the dissolution of each of the components.

Evaporation is another factor involved when it comes to describing dissolution. Indeed, the solubility and volatility of the components are very strongly correlated; more soluble a compound, the more volatile it is.

Mass transfer due to evaporation predominates on that of dissolution. Thus, the mass of the oil slick decreases over time. This depletion within slick reduces the rate of transfer of dissolved matter into the water and there may be direct evaporation of the dissolved components in the water.

III.2. A phase of long-term

This phase takes place over weeks, months or even years. This second phase of evolution is associated with the phase of decontamination of the marine environment as result of the energy level of the contaminated sites:

III.2.1. Mechanical energy of the environment: natural dispersion

The dispersal at sea is caused by wave breaking which splits the slick into droplets of different sizes. These droplets are submitted to vertical movements related to their buoyancy and turbulence in the environment. Smaller droplets, with reduced buoyancy, will tend to stay in the water column or begin to flow, while the large droplets will resurface at the back of the slick. Indeed, surface slick moves by wind and current effect, while the droplets within the water column are submitted by current effect. Those moves less rapidly than the surface water when resurface, they are located behind the slick (Elliott et al.,1986).

III.2.3. Solar energy: photo-oxidation

Photo-oxidation is a process of oxidation of the silk as a result of ultra-violet solar radiation. This process, negligible in the first few hours, it's gains importance after a week.

III.2.3. Biological energy: biodegradation

Biodegradation is due to the presence of micro-organism in the water it may take several years. Whether some processes are well understood such as spreading and evaporation the others not well enough known (photooxidation and biodegradation). All these phenomena are not currently modeled and have not been well-studied.

IV. A Lagrangian-based maritime and coastal risk model formulation

In the literature, the oil spill represents one of the main concerns in the context of risk analysis of maritime transportation due to the potential impact on marine ecosystems, to socio-economic activities and to the huge efforts in terms of recovery and clean-up operations (Nelson et al., 2018; Xin Liu et al., 2009; Burgherr, 2007).

Different risk definitions exist in the literature involving components such as probability, uncertainty, frequency of specific events, and/or related consequences. In (Goerlandt et al., 2015), a review of methods and applications for maritime transportation risk analysis have been presented.

In the proposed approach, the risk (R) is associated with the expected value of the probability (P) of an accident occurrence with a given spill size in a specific sea area and the outcome arising as a consequence (C) of the oil slick movement (Goerlandt et al., 2015). The risk (R) is defined as probability (P) times consequence (C), (CCPS, 2008):

$$\boldsymbol{R = P \times C} \qquad (1)$$

IV.1. Accident probability analysis

The probability of maritime traffic accident occurrence is usually modelled by statistical approach which is based on historical documentations about accident and non-accident rates, failures equipment, spill or release probabilities and container designs.

In the proposed model, the oil spill probability P_i, at the marine location *i-th*, is computed throug the combination of three different components:

$$\boldsymbol{P_i = AR_i \times P_{spill\,size} \times P_i^{weather}} \qquad (2)$$

Where:

$\boldsymbol{AR_i}$ is the yearly accident rate for a specific geographic region which the location *i-th* belongs to. Assuming to be known a set of statistical data about accidents occurred in a predefined sea area, AR_i may be computed as

$$\boldsymbol{AR_i = \frac{\#\,oil\,spill\,accident}{\#\,years * area}\left[\frac{\#accident}{yr\,km^2}\right]} \qquad (3)$$

- $\boldsymbol{P_{spill\,size}}$, is the probability of different release sizes in case of the accident occurrence. Three release sizes were defined: small (release <70 tons), medium (release between 70 and 7000 Ton) and large (release > 7000 Ton).

-

$$\boldsymbol{P}_{spill\ size} = \frac{\#\ accidents\ \ for\ each\ category\ of\ oil\ spill\ size}{\#\ Total\ accidents} \quad (4)$$

- $\boldsymbol{P}_{i}^{weather}$**:** the probability of weather stability, in the location *i-th*, which represents the probability of different combinations of atmospheric conditions for wind speed and directions based on frequency analysis. Statistical data are available in open-source database for different Mediterranean areas.

IV.2. Consequence modelling

Currently, the consequence modelling is classified into two generations models according to their analysis in two or three dimensions (2D and 3D models). Those models have been developed to predict the evolution and behavior of hydrocarbons spilled on the surface and into the deepwater. This choice of dimension analysis directly influences the complexity of the model and the accuracy of the expected results. The 2D models (A Hardeo, 2011; Janeiro et al., 2008; Vethamony et al., 2007; Wang et al., 2005; Beegle-Krausel, 2001; Chao et al., 2001) run quickly but they do not allow to obtain detailed information on the water column contamination (Cedric, 2012) focusing only on the study of surface transport processes (Malcolm, 2017). The 3D models (El-Fadel et al., 2012; Wang et al., 2008; Carracedo et al., 2006) provide a description of the flow over the entire water column (surface, subsurface transport and fate processes) (Malcolm, 2017). The latter models will give rise to more accurate results to simulate oil spills, yet more parameters have to be defined to get precise results. The decision to develop a 2D or 3D model strongly depends on the data that would be available to use as inputs. Upon the occurrence of a spill incident, the oil may stagnate as suspensions in the water column for a prolonged period due to the formation of emulsions. When emulsions processes are formed, the impact of the spill increases. As a consequence, the response and cleaning efforts become more complicated. Inclusion of the vertical movement of particles often makes the model very complex, as it will require detailed oceanographic information about the region for which the model is developed (Hardeo et al., 2016).

The 2D spreading models are based mostly on the Lagrangian approaches (Cedric, 2012). The Lagrangian based models consider the oil slick as the movements of a set of small droplets subjected to wind, waves, and currents, and which can rise or sink due to buoyancy (Nordam et al., 2019). Several studies use the Lagrangian model to determine the areas that would be affected in the event of an oil spill (Kankara, 2016; Xu et al., 2013; Marta-Almeida et al., 2013; Delpeche et al., 2013; Xu et al., 2012; Havens et al., 2009).

In the proposed approach, a 2D Lagrangian based consequence model has been defined and used to compute maritime risk. The spreading, advection and diffusion processes which draw the oil spill trajectory and the consequently impacted area of the spill accidents are described in the following paragraphs.

Spreading is one of the most relevant processes, not only because it guarantees the prediction of the extent of oil slick area. But also, because it affects all other oil slick transformation processes.

Two physical phenomena lead to an oil slick movement on the surface water. First, the slick is subject to the spreading process under the influence of mechanical forces such as gravity, inertia, viscosity and interfacial tension and, on the other hand, to turbulent diffusion.

The oil slick extension in the wind direction is expected to increase with time proportionally to the wind speed, while the lateral elongation is always described by the gravity-spread equation described by Fay (Fay, 1971).

The Fay spreading model (Fay, 1971) is one of the most widely used models (ASCE, 1996; Cekirge et al., 1995). It divides the spread of the oil slick into three phases. In the first phase (gravity inertial stage), which lasts one hour, the slick is subjected to gravity forces balanced by inertia forces. During the second phase, so-called gravity viscous spreading, which may be extended to a week, gravity and viscosity forces prevail. Beyond the week, only the viscosity is taken into account.

According to (Fay, 1971), the time t_0 which concludes the first gravity inertial phase may be computed as follows:

$$\boldsymbol{t_0} = \left(\frac{k_2}{k_1}\right)^4 \left(\frac{V_0}{\vartheta_m\, g\Delta\rho}\right)^{1/3} \tag{5}$$

Where:

- k_1 and k_2 are empirical coefficients (k_1 = 1.14 and k_2 =1.45 (Fay, 1971));
- V_0 is volume of oil spilled (m^3);
- ϑ_m is the kinematic viscosity of water(m^2/s);
- g is gravitational acceleration(m/s^2);
- $\Delta\rho$ is the relative density difference between the water and oil given by:

$$\boldsymbol{\Delta\rho} = \frac{\rho_w - \rho_{oil}}{\rho_w} \tag{6}$$

Where ρ_w is the density of water $(g/cm^3)$and ρ_{oil} is the density of oil (g/cm^3).

The area A_o affected by the oil spreading at time t_0, at the end of the gravity inertial phase, may be computed by eq.(7).

$$\mathbf{A_0 = \pi \frac{k_2{}^4}{k_1{}^2}\left(\frac{V_0{}^5 g\Delta\rho}{\vartheta_m{}^2}\right)} \tag{7}$$

In the next gravity viscous spreading phase, the area $A(t)$ of the oil slick during the time horizon may be computed using a correlation developed by (Berry, 2012), which assumes that oil slick spreading may have an elliptical shape on the water's surface with the major axis oriented in the direction of the wind.

The area covered by the oil slick, A_t , at time *t-th,* from the time t_0 , is described by

$$\boldsymbol{A_t = \frac{1}{4}\pi Q_t R_t} \tag{8}$$

The length of the minor ellipse axis, Q_t, is given by (9):

$$\boldsymbol{Q_t = 1.7(\Delta\rho V_0)^{1/3} t^{1/4}} \tag{9}$$

where V_0 is the volume of oil spill, the time *t-th* is the number of time units starting from the time t_0,

The length of the major axis of the ellipse, R_t, is described by

$$\boldsymbol{R_t = Q_t + 0.03 * (U_{wind})^{4/3}(t)^{3/4}} \tag{10}$$

Where U_{wind} is the wind speed.

■ Advection and diffusion

The transport of an oil slick is generally induced by surface current, wind, waves and turbulent diffusion. Indeed, 60 to 65% of the oil slick remains on the surface. Wind and currents are the two major processes composing the phenomenon of advection the slick. This surface current is largely wind generated, but in high tides regions tidal currents may dominate.

In this two-dimensional model of oil spill, the initial area of oil slick is divided into a large number of distinct Lagrangian particles in a XY plane reference at the water surface where (xt, yt) represent the position of a particle at a time step t.

It is assumed that these particles are connected to the surrounding body of water and therefore diffuse from a random process. The advection and diffusion properties of each particle can be calculated based on the flow fields at the water surface and the wind speed. Consequently, the speed, as well as the displacement of these particles, can be solved. Once their coordinates are determined at each time step, the shape and trace of the spill can be decided.

- ***Advection velocity***

A large number of models of oil slick drift use a constant parameter to relate the surface wind speed to the drift of the slick. This parameter is taken equal to about 3.5% for wind speed (Berry, 2012; Periáñez et al., 2010; Guo et al., 2009; Ambjorn, 2007; McCay-French, 2004; ASCE, 1996; Al-Rabeh et al., 1989). The oil slick is then supposed to drift on water at 3.5% of the wind speed combined with 100% of the current speed. The advective velocity (Ua) of the oil slick due to wind (Uwind) and surface current (Ucurrent) effects is given (Berry, 2012):

$$\boldsymbol{U_a = U_{current} + 0.035\, U_{wind}} \quad (11)$$

Where U_a is the advective velocity of the oil slick (m/s), $U_{current}$ is the surface current (m/s) and U_{wind} is wind speed (m/s).

- ***Horizontal turbulent diffusion***

Generally, the Lagrangian approach represent the turbulent diffusion considering that the surface or suspended particles of the slick are subject to a random movement in addition to the regular movement due to the main current in the sea (Wang et al., 2008).

The translations, respectively ΔX_{diff} and ΔY_{diff}, due to the diffusion phase, during a time step *Δt* of the particles in the X and Y directions are based on (Al-Rabeh, 1989):

$$\Delta \boldsymbol{X_{diff} = [R]_0^1 \sqrt{12 D_h \Delta t} cos\theta} \quad (12)$$

$$\Delta \boldsymbol{Y_{diff} = [R]_0^1 \sqrt{12 D_h \Delta t} sin\theta} \quad (13)$$

Where $[R]_0^1$ is a random number between 0 and 1 from a uniform distribution, D_h: horizontal diffusion coefficient; and θ is the directional angle $\theta = 2\pi R$.

Thus, the displacement of the oil slick due to advection and horizontal diffusion is given as (Berry et al., 2012):

$$\mathbf{X_{t+1} = x_t + u_{a,x}(x_t, y_t)\Delta t + \Delta x_{diff}} \quad (14)$$

$$\mathbf{Y_{t+1} = y_t + u_{a,y}(x_t, y_t)\Delta t + \Delta y_{diff}} \quad (15)$$

Where:

- x_t, y_t is the location of the particles at time step *t-th*,
- $u_{a,x}$ and $u_{a,y}$ are the advective velocities in the *X* and *Y* directions respectively,
- Δt is the time-step interval (s)
- ΔX_{diff}, ΔY_{diff} are the displacements of the particles in the *X* and *Y* directions respectively.

V. Case study in the Mediterranean Sea (incident of Saint Tropez)

The proposed model has been tested to evaluate the oil spill propagation in the case of the accident in the Tyrrhenian Sea occurred of the coast of Corsica on October 7th 2018, between a Cypriot container ship and a Tunisian ship. According to public authorities estimation, the accident consisted in a release of about 600 m^3 of oil (Vazquez, 2018) (figure 47 & 48).

Figure 47: Aerial view of boats collided off the coast of Corsica, 10 October 2018 (Source: (AFP, 2018))

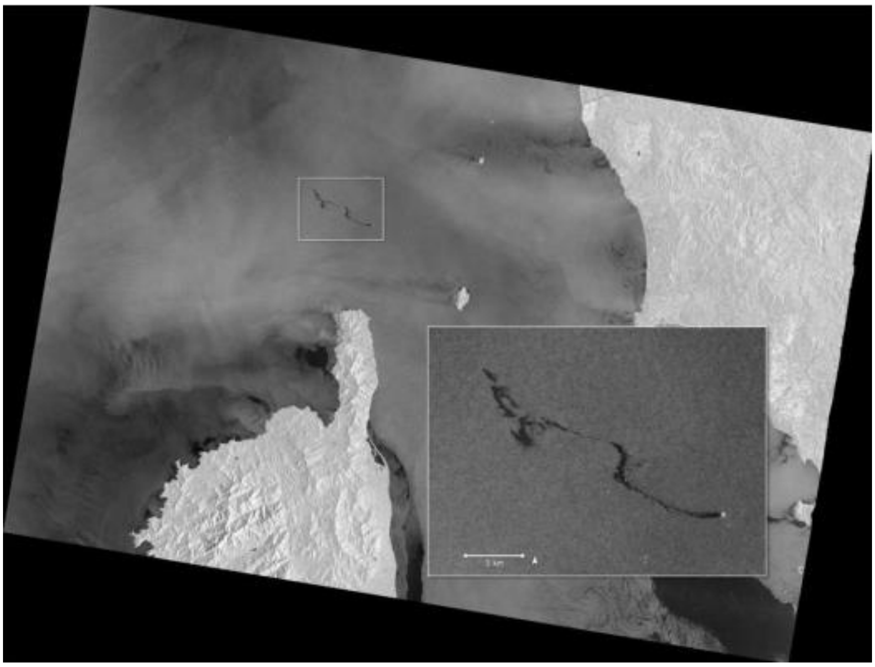


Figure 48: A satellite image of the alleged fuel slick at the origin of this pollution, taken the day after the collision between the two ships
(Source: .(https://www.futura-sciences.com/planete/ 2018))

V.1. Weather conditions

In order to apply the proposed method, a whether condition analysis in the selected area for the time horizon of 9 days starting from the October 7th, 2018 has been carried out. The main environmental information necessary for reliable prediction of oil slick movement are related to the wind, water surface current, and waves that varied in time and space. Accurate information of these dynamic forcing conditions is important and fundamental to produce a precise model of oil spill trajectory.

During the incident period (9 days), the wind blew ranging from 13 km/h to 46 km/h, predominantly in the north-east direction according to data coming from the database Spanish Network of Measurements (REMRO Network), although the wind turned during all the compass. The Table 42 shows the values of the wind speed during the selected period in the coastal area of Saint Tropez. Besides, the surface current of the sea water was about 1 m/s during the overall period. The figure 49 displays the wind rose averages in the incident area during the incident period.

Table 42: The values of the wind speed during the 9 days after the accident.

Date	**Wind Speed**	
	Km/h	***m/s***
07 October 2019	13	3.6
08 October 2019	36	10
09 October 2019	29	8.05
10 October 2019	44	12.22
11 October 2019	29	8.05
12 October 2019	14	3.88
13 October 2019	17	4.72
14 October 2019	34	9.44
15 October 2019	46	12.77

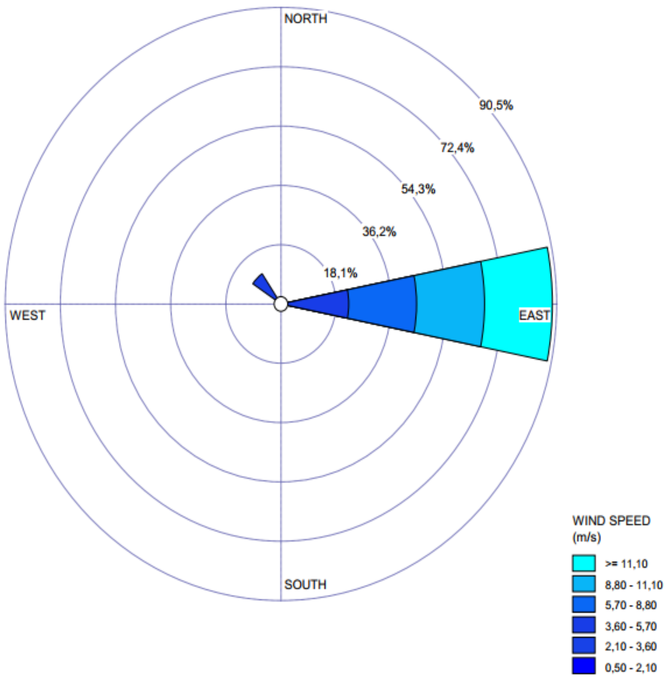


Figure 49 : Monthly Wind Rose averages in the incident area during the incident period (October)

Due to the high-speed values for wind (>8 m/s) in that period, the public authorities didn't have the possibility to apply recovery actions before the oil slick arrived on the coast. Oil residues reached the French beaches, including Pampelonne in the Gulf of Saint-Tropez, within nine days after the collision of two ships off the French island of Corsica. More than16 kilometres (10 miles) of coastline had been affected by the spill. Nearly 50 beaches were affected in 11 French municipalities: Escalet, Pampelonne in Ramatuelle, Salins and Moutte in

Saint-Tropez, La Nartelle-Saint Barth in Sainte-Maxime were closed to public (le nouvelliste, 2018).

V.2. Model application

The proposed model was applied to simulate the trajectory of the spilled oil for the selected case study in 9 days from the 7th to 15th October 2018.

In the simulated scenario, from the beginning of the incident, in the first 24 hours, the oil slick was directed toward south-west and it covered a distance approximately of 6 km. In the real case, the observed data confirmed that the model predicts quite accurately the horizontal movement of the surface oil slick.

In the simulated scenario, from October 8th to 9th, the oil slick travelled a distance approximately of 15km. During the fourth day, when a very high wind speed (44 km/h) has been observed, the oil slick covered a distance approximately of 50km. From the 11th to the 13th October, the oil slick travelled a distance approximately of 87 Km. During the period from October 14th to 15th, the oil slick moved in the direction of Saint Tropez spreading for more than 160 km.

The simulation results about the movements of the oil slick during the incident period shows that the trajectory and timing obtained by the proposed model correspond approximatively with the actual trajectory and timing carried out by the oil spill slick in the real case study in the Tyrrhenian Sea.

In 9 days, the oil spill slick reached the coast out Saint Tropez covering about 230 km. The same results are obtained by the proposed model simulation for the oil slick propagation. Figure 50 displays the actual distance covered in the selected time horizon. While figure 51 shows the simulated distribution of oil spill for each day of the time horizon. Both in the real and in the simulated results, the oil slick travelled about 230 km in the selected 9 days. This underlines that the gap between the real observations and the modelled results is minimum.

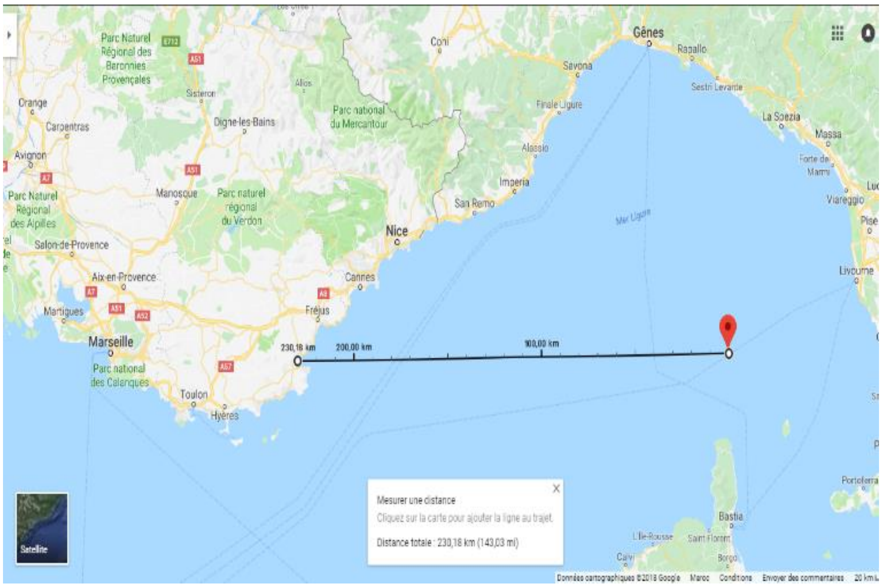


Figure 50: Actual distance covered by the oil slick in the selected 9 days.

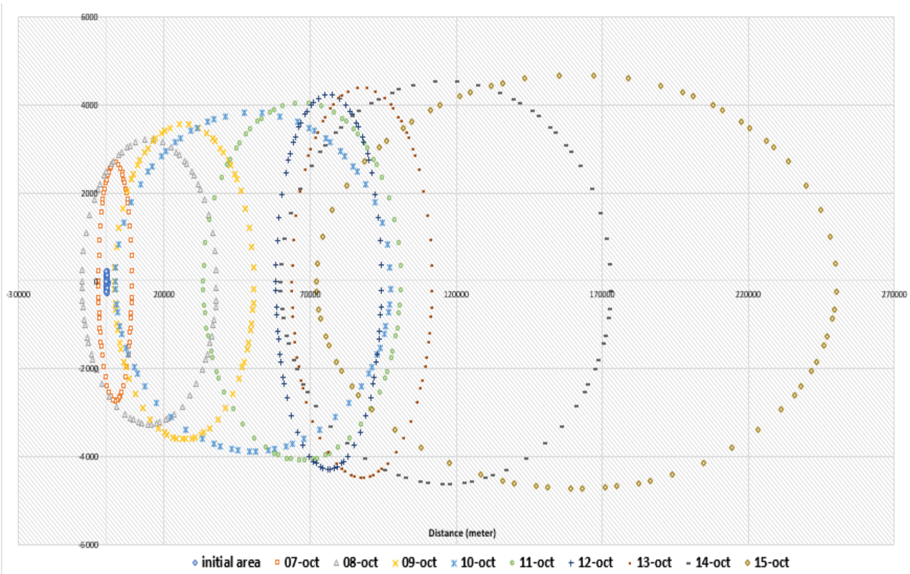


Figure 51: Distribution of oil spill assessed by the elliptical shapes computed according to the proposed model

The dimensions of the impacted area, computed by eq. (12) to eq. (15), during the time horizon of 9 days, are listed in the table 43.

The simulation of oil slick trajectory during the study period (9 days) is shown in the graphs in figure 52 which consists of consecutive elliptical shapes, whose dimensions appear in Table 43, computed according to the proposed model.

Table 43: values of the variables to predict the oil slick spreading.

Date	**Wind speed (m/s)**	**A_t (km^2)**	**Length Q (m)**	**Length R (m)**	**Distance between the accident source point and the further point of the oil slick**
07-oct	3.6	6.27	2722.3	5694.8	8.70
08-oct	10	9.14	3237.4	23049.2	37.58
09-oct	8.05	11.44	3582.8	23851.5	50.31
10-oct	12.22	13.45	3849.9	47169.0	97.21
11-oct	8.05	15.28	4070.8	33802.1	100.74
12-oct	3.88	16.98	4260.7	18078.1	94.06
13-oct	4.72	18.57	4428.1	24000.5	111.98
14-oct	9.44	20.09	4578.4	56563.1	172.82
15-oct	12.77	21.54	4715.2	89038.3	249.82

Figure 52 displays a map generated by a geographical information system (GIS) related to the simulated propagation of the oil slick in the different days with different colours.

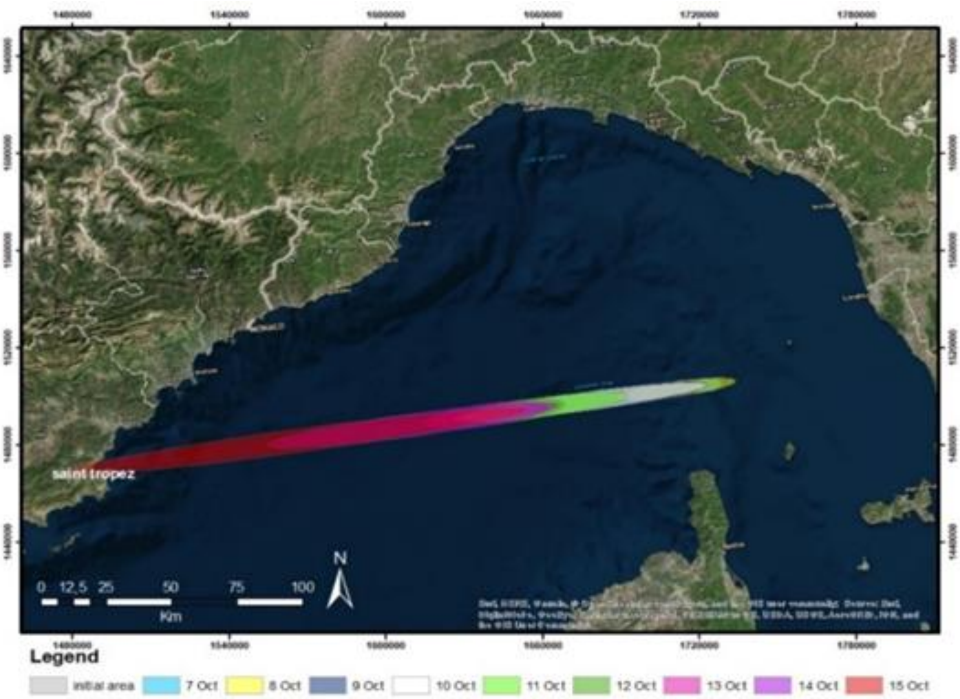


Figure 52: Trajectories of oil slick simulated by the model from October 7 to October 15, 2018. (Source: (Soussi et al., 2019)

VI. Case Study: Strait of Gibraltar

Due to its strategical position and its busy maritime traffic, represents the main maritime highway in West Mediterranean. The Strait occupies the space where the dense commercial traffic fueling between Europe and Asia intersects, revealing the historical links between Europe and Africa. These flows raise the Strait of Gibraltar to the ranks of the Straits of Pas de Calais or Malacca in terms of international maritime traffic (97,000 to 100,000 vessels per year) and, besides, the nature of these flows makes it an observatory area of global trade (Mareï, 2012).

In this study, it is assumed that oil spill models to simulate the evolution of an oil slick and to compute the related risk assessment are based on maritime accidents or accidental ship collisions which may occur in four different sites in the body of water of the Gibraltar Strait. The consequence models are tested to evaluate the impact of the simulated accident scenarios on 8 sensible Point of Interests (POIs) located on the African and European coast, namely Tanger, Port Tanger Med, Dalia beach, Oued Marsa beach, Ceuta for Africa, and Tarifa, Algéciras and Gibraltar for Europe. Figure 53 represents the geographical position of the selected potential accident test sites (ATSs) and the location of the sensible coastal locations (POIs). Table 44 shows the geographical coordinates of the ATSs and the related distances from the specific POIs on the Moroccan and Spanish coasts. In order to simulate the evolution of the oil slick, wind speed and wind directions data have been collected by REMRO database (REMRO, 2018). Those data related, as an example, to the ATS 1 appear in the table 45.

Table 44: The distance among the ATSs and the coastal POIs.

Point of Interest			Distance (km)			
			ATS 1 ***(35°57'06.5"N 5°37'04.2"W)***	**ATS 2** ***(35°58'11.7"N 5°28'00.8"W)***	**ATS 3** ***(35°58'22.5"N 5°26'30.2"W)***	**ATS 4** ***(35°59'03.9"N 5°20'44.8"W)***
MOROCCO	**POI1**	Tanger	24.56	36	38.5	46
	POI2	Port Tanger Med	12.42	9.19	10.46	17.22
	POI3	Dalia beach	13.84	7.25	8.13	14.78
	POI4	Oued Marsa beach	16.64	7.63	7.56	12.71
	POI5	Ceuta	28.86	16.78	15	11
SPAIN	**POI6**	Tarifa	6.34	12.87	14.77	23
	POI7	Algésiras	10	9.45	10.5	12.91
	POI8	Gibraltar	29.89	19	18	14

Table 45: Annual distribution of wind direction and mean wind speed for ATS 1

Direction	average wind speed (m/s)								
	≤ 1.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0	>21.0
Calm	1.056								
N		0.666	1.159	0.361	0.028	-	-	-	-
NNE		0.643	0.779	1.145	0.005	-	-	-	-
NE		0.620	0.948	0.122	0.019	-	-	-	-
ENE		0.554	1.952	1.638	0.671	0.155	0.005	-	-
E		0.634	3.731	7.824	8.406	4.581	1.572	0.347	-
ESE		0.451	1.525	1.253	0.554	0.160	0.038	-	-
SE		0.399	0.742	0.164	0.023	-	-	-	-
SSE		0.399	0.549	0.169	0.047	0.005	-	-	-
S		0.432	0.878	0.446	0.155	0.005	0.009	0.005	-
SSW		0.577	1.197	0.986	0.634	0.183	0.094	0.009	-
SW		0.840	2.647	1.492	0.882	0.451	0.066	0.009	-
WSW		1.197	4.163	1.835	0.605	0.286	0.042	-	-
W		1.370	5.890	3.173	0.849	0.197	0.005	0.019	-
WNW		1.352	6.251	2.816	0.807	0.169	0.052	-	-
NW		1.028	4.224	1.915	0.512	0.089	0.005	-	-
NNW		0.869	2.215	0.803	0.131	0.009	-	-	-

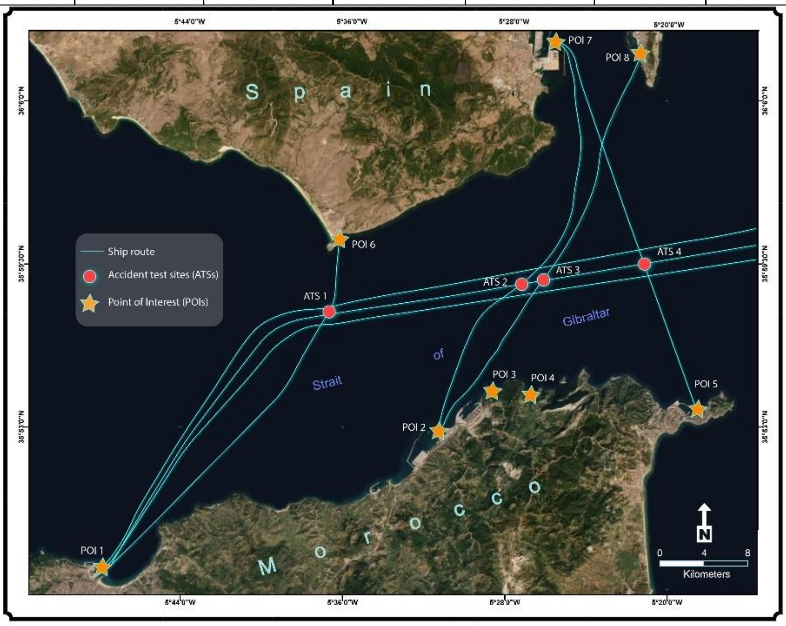


Figure 53: Location of accident test sites for simulations in the case study in Gibraltar Strait

VI.1. Model application

In the proposed study, the yearly accident rate for the case study area, computed by eq. 3, is based on REMPEC accidents data related to accidents occurred in 40 years, from 1977 to 2017, in Western Mediterranean Sea. Thus $AR = 7.83\string^ - 06$ accident /yr km^2.

The consequence analysis has been carried out taking into account the following conditions:

- three release sizes have been defined (70, 700 and 7000 tons). Table 46 contains the $P_{spill\ size}$ computed by eq.4 according to accident data in the period 1977–2017.

- three U_{wind} for 8 different directions (N, NE, E, SE, S, SW, W, NE) are considered in simulations, namely U_{wind} =1.5, 14 and 24 m/s. As an example, the probability of different combinations of atmospheric conditions for U_{wind}=14 m/s in different ATSs are listed in table47.

In the proposed simulations, the surface current in the four ATSs has been considered $U_{current} =$ 0.6 m/s according to data coming from (Tsimplis et al., 2000; Perkins et al.,1990). Concerning the horizontal diffusion coefficient, the value $D_h = 7$ m^2/sec (Chao et al., 2001) has been adopted in the applications.

Table 48 indicates the oil spill probability P computed by eq.2 as the combination of these three different components in case of the bigger release category of 700 Ton oil spilled.

About 288 simulations have been carried out to evaluate the risk assessment on the sensible POIs sites on the African and European coasts. The simulations consist in four potential maritime accidents (ATS1, ATS2, ATS3, ATS4) with three spill categories (70, 700 and 7000 tons), for three different wind speeds (1.5, 14 and 24 m/s) in eight wind directions.

Table 46: $P_{(spill\ size)}$ computed according to the accident data in the period 1977-2017.

Release size (Tons)	**Number of accident**	$\boldsymbol{P_{spill\ size}}$
70	261	6.92E-01
700	72	1.91E-01
7000	44	1.17E-01

Table 47: Probability of different combinations of atmospheric conditions for wind speed as 14 m/s in 8 different directions.

Wind speed m/s	Direction	Test sites			
		ATS 1	ATS 2	ATS 3	ATS 4
14	N	5.00E-03	5.00E-03	5.00E-03	5.00E-03
	NNE	5.00E-03	5.00E-03	5.00E-03	5.00E-03
	NE	5.00E-03	5.00E-03	5.00E-03	5.00E-03
	ENE	1.00E-02	5.00E-03	5.00E-03	5.00E-03
	E	2.10E-01	3.20E-02	3.20E-02	1.50E-02
	ESE	2.00E-02	3.00E-02	3.00E-02	3.00E-02
	SE	5.00E-03	5.00E-03	5.00E-03	5.00E-03
	SSE	5.00E-03	1.00E-02	1.00E-02	1.00E-02
	S	5.00E-03	5.00E-03	5.00E-03	5.00E-03
	SSW	2.00E-02	1.00E-02	1.00E-02	1.00E-02
	SW	2.00E-02	1.25E-02	1.25E-02	1.20E-02
	WSW	5.00E-03	3.00E-02	3.00E-02	2.00E-02
	W	1.00E-03	5.00E-03	5.00E-03	1.00E-02
	WNW	5.00E-03	5.00E-03	5.00E-03	5.00E-03
	NW	5.00E-03	5.00E-03	5.00E-03	1.50E-02
	NNW	5.00E-03	5.00E-03	5.00E-03	1.00E-02

Table 48: The probability Pi for a 700 T oil spill release.

Quantity (T)	Direction	Wind speed (m/s)											
		1.5				**14**				**24**			
		PATS1	**PATS2**	**PATS3**	**PATS4**	**PATS1**	**PATS2**	**PATS3**	**PATS4**	**PATS1**	**PATS2**	**PATS3**	**PATS4**
700 T	N	1.72E-07	3.89E-07	3.89E-07	2.84E-07	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	NNE	1.35E-07	1.50E-07	1.50E-07	2.84E-07	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	NE	2.69E-07	2.09E-07	2.09E-07	5.98E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	ENE	5.98E-08	5.98E-08	5.98E-08	1.35E-07	1.50E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	E	1.35E-08	7.48E-09	7.48E-09	7.48E-09	3.14E-07	4.79E-08	4.79E-08	2.24E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	ESE	5.98E-08	2.84E-07	2.84E-07	2.09E-07	2.99E-08	4.49E-08	4.49E-08	4.49E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	SE	2.84E-07	4.34E-07	4.34E-07	3.59E-07	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	SSE	1.35E-07	2.99E-07	2.99E-07	2.24E-07	7.48E-09	1.50E-08	1.50E-08	1.50E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	S	2.69E-07	5.83E-07	5.83E-07	2.84E-07	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	SSW	5.98E-08	1.35E-07	1.35E-07	1.35E-07	2.99E-08	1.50E-08	1.50E-08	1.50E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	SW	1.72E-07	2.84E-07	2.84E-07	2.39E-07	2.99E-08	1.87E-08	1.87E-08	1.79E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	WSW	5.98E-08	5.98E-08	5.98E-08	1.50E-08	7.48E-09	4.49E-08	4.49E-08	2.99E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	w	2.99E-08	7.48E-09	7.48E-09	7.48E-09	1.50E-09	7.48E-09	7.48E-09	1.50E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	WNW	5.98E-08	5.98E-08	5.98E-08	5.98E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	NW	1.11E-06	1.35E-07	1.35E-07	1.35E-07	7.48E-09	7.48E-09	7.48E-09	2.24E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09
	NNW	7.48E-09	7.48E-09	7.48E-09	1.50E-08	7.48E-09	7.48E-09	7.48E-09	1.50E-08	7.48E-09	7.48E-09	7.48E-09	7.48E-09

VI.2. Consequence model simulations

In this section, the simulation results for the three different spill release sizes have been presented and compared in relation to different meteorological conditions.

The calculation of the impacted area A_t computed by the model (5)-(15) for the three different release scenarios during the nine hours after the accident happened (wind speed =14 m/s) is lis ted in table 49. Figure 54 displays the related graphical interpretation of the oil slick spreading

Figure 55 and 56 represents the visualization, by a GIS, of a simulated scenario which concerns a maritime spill accident, occurred in the ATS4, with an estimated spill release of 700 tons with $U_{wind} = 14\ m/s$ and wind direction Northeast-East (NE), and figure shows the estimation of a spill of 7000 tones rejection with $U_{wind} = 14\ m/s$, and a North-West wind direction (NW) occurred in the ATS1. (the others scenarios are in appendix 2)

Table 49: The computation of the elliptical A_t spreading for the oil slick during 9 hours after the incident occurring

Wind speed (m/s)	Release size (Tons)	Time (hours) *	At (km2)	Length Q (m)	Length R (m)
14	**700**	1	1.53	1346.36	3075.49
		2	2.23	1601.10	4509.14
		3	2.79	1771.91	5713.48
		4	3.28	1904.04	6794.76
		5	3.72	2013.28	7794.98
		6	4.13	2107.17	8736.07
		7	4.52	2189.96	9631.31
		8	4.88	2264.30	10489.48
		9	5.23	2331.97	11316.80
	7000	1	6.71	2900.03	4629.16
		2	9.56	3448.74	6356.78
		3	11.76	3816.66	7758.23
		4	13.64	4101.27	8991.99
		5	15.31	4336.56	10118.26
		6	16.82	4538.80	11167.70
		7	18.23	4717.13	12158.47
		8	19.54	4877.26	13102.44
		9	20.78	5023.01	14007.84
	70	1	0.41	625.72	2354.85
		2	0.65	744.11	3652.15
		3	0.85	823.49	4765.06
		4	1.04	884.90	5775.62
		5	1.22	935.67	6717.37
		6	1.40	979.30	7608.20
		7	1.56	1017.78	8459.13
		8	1.73	1052.33	9277.51
		9	1.89	1083.78	10068.61

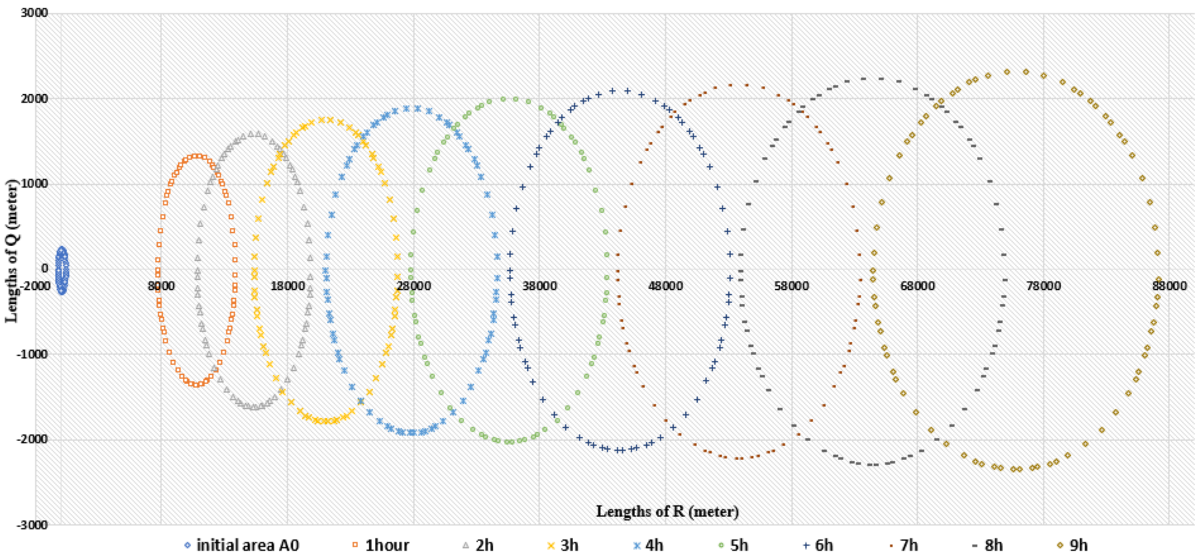


Figure 54: Elliptical spreading of a surface slick for 700 T Tons spilled with wind speed 14m/s

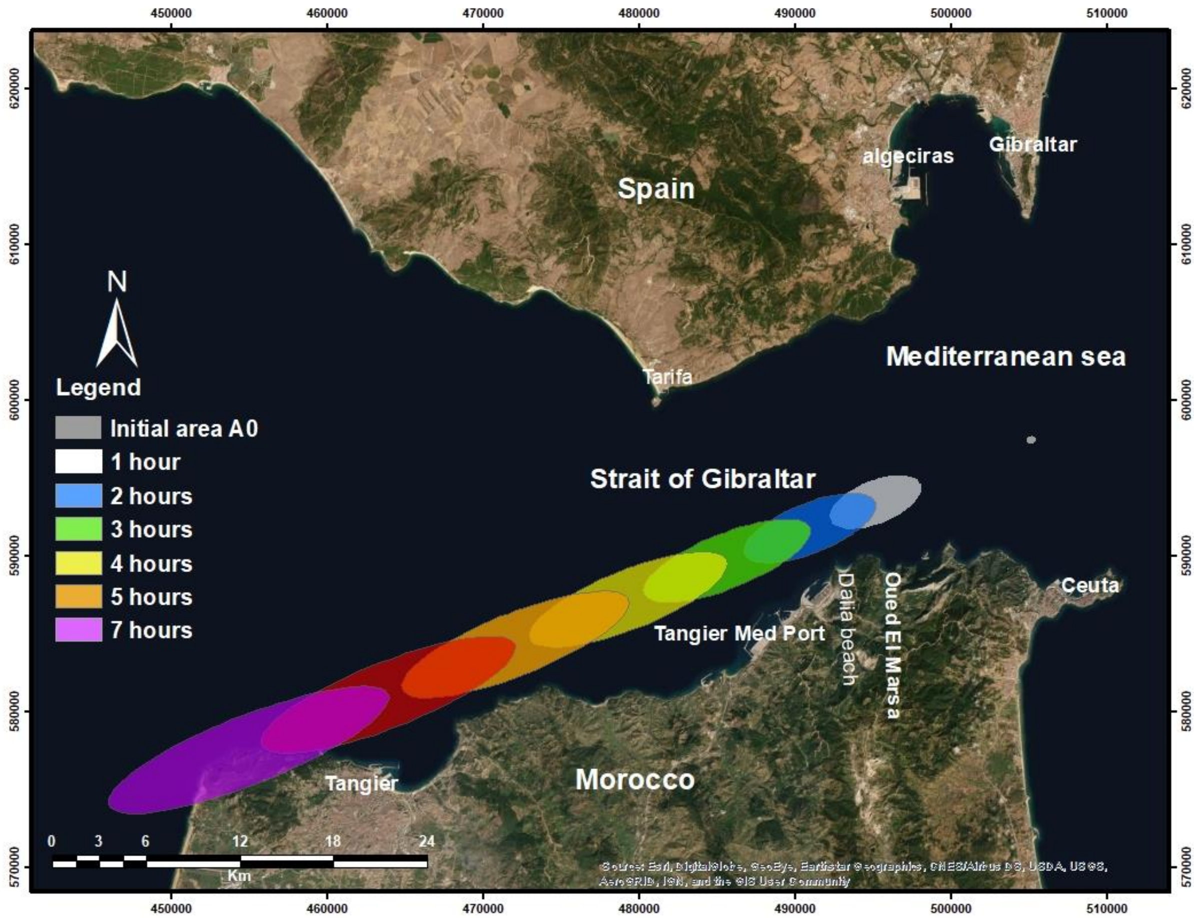


Figure 55: Estimated Spill location for 700 Tons from test point 4 with wind speed 14 m/s (wind direction: Northeast-East)

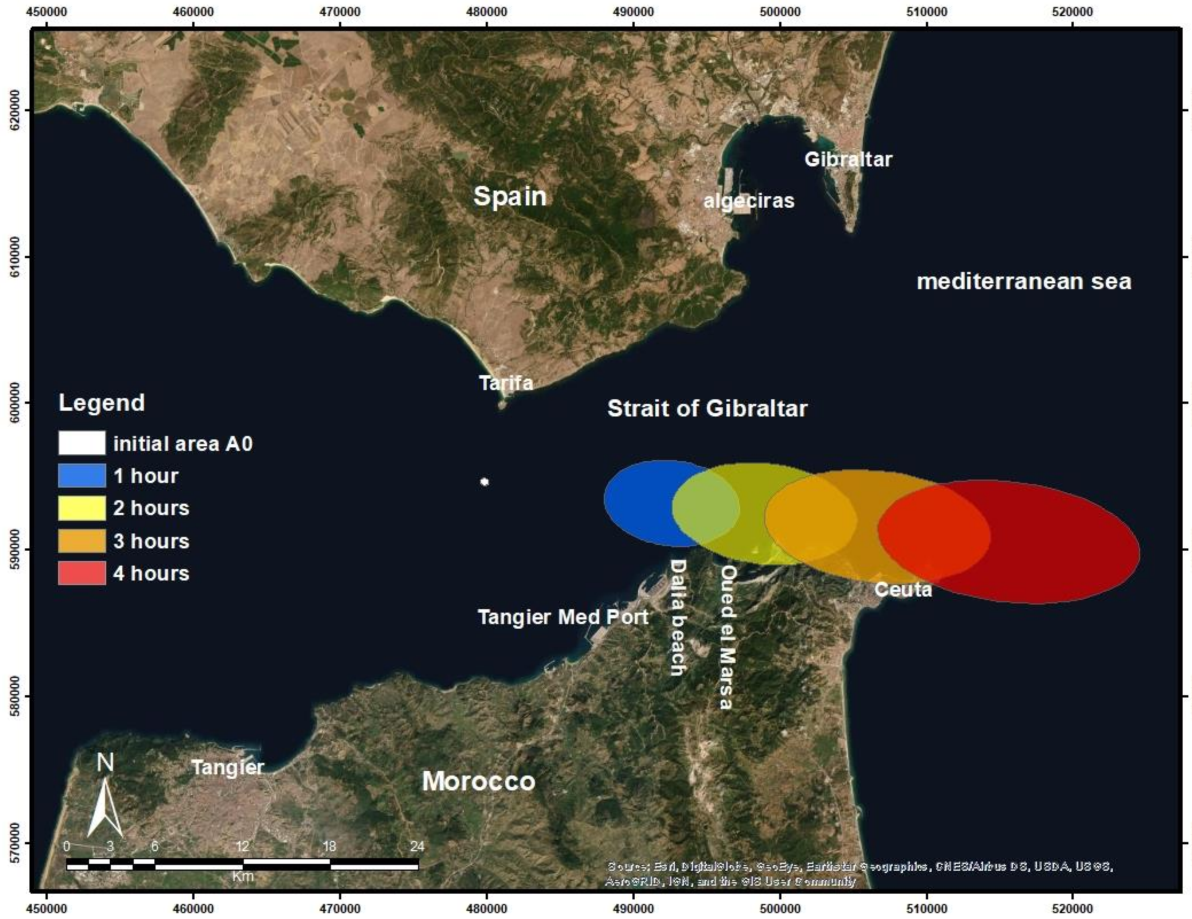


Figure 56: Estimated Spill location for 7000 Tons from test point 1 with wind speed 14 m/s (wind direction: NW)

VI.3. Risk model application

In order to evaluate the environmental risk due to coastal pollution occurring in the event of a spill accident, it is necessary to identify risk's levels. In the proposed model, the potential environmental risk was assessed on the basis of the time required by the oil slick to reach the European and African coasts assuming that an oil spill accident may have occurred in one of the ATSs.

The proposed Lagrangian-based maritime and coastal risk model can be used not merely in oil spill response and contingency planning but also in assessment risk impact. In the event of an oil spill, by a limited set of necessary meteorological data, the predictions of the slick movements and trajectories may be provided to the competent authorities. The main result of the proposed approach is the possibility to define a risk ranking for the coastal area based on the forecasted slick movements and to determine, under specified meteorological conditions, the time required by the oil slick to hit the littoral.

The tables 50 and 51 represent the estimated times (in hours) required by the oil spill to reach the POIs in the African and European coasts coming from the different ATSs off the Strait of Gibraltar according to different scenarios.

Table 50: Time (hours) required by the oil slick to reach the POIs on the Moroccan coastile for accidents occurred in one of the ATSs.

				Release quantity								
				70 T			**700 T**			**7000T**		
Wind speed [m/s]				***1.5***	***14***	***24***	***1.5***	***14***	***24***	***1.5***	***14***	***24***
AFRICAN PART	**Time (hour)**	**Tangier**	**P1**	12	4.5	2.5	8	3.5	2.5	3.5	2	1.5
			P2	17.5	7	4	12	5	3.5	7	3.5	3
			P3	18.5	7.5	4	12.5	5	3.5	7.5	3.5	3
			P4	21	8.5	4.5	15	6	4.5	8.5	4	3.5
		Port Tanger Med	**P1**	6	2	1	3.5	1.5	<1	2	<1	<1
			P2	4	1	<1	2	1	<1	1	<1	<1
			P3	4	1.5	<1	2.5	1	<1	1	<1	<1
			P4	9	3	1.5	5.5	2.5	1.5	3	1	1
		Dalia beach	**P1**	6	2	1	4	1.5	1	2	<1	<1
			P2	2	<1	<1	1	<1	<1	<1	<1	<1
			P3	2.5	<1	<1	1.5	<1	<1	<1	<1	<1
			P4	7	2	1.5	4.5	2	1	2	<1	<1
		Oued Mersa beach	**P1**	8	3	1.5	5	2.5	1.5	3	<1	<1
			P2	2	<1	<1	1	<1	<1	<1	<1	<1
			P3	2	<1	<1	1	<1	<1	<1	<1	<1
			P4	6	2	1	3.5	1.5	<1	2	<1	<1
		Ceuta	**P1**	14.5	5.5	3	9.5	4	2.5	5.5	2.5	2
			P2	8	3	1.5	5	2.5	1.5	3	<1	<1
			P3	7.5	2.5	1.5	4.5	2	1.5	2.5	<1	<1
			P4	5	1	1	3	1	<1	1.5	<1	<1

Table 51: Time (hours) required by the oil slick to reach the POIs on the Spanish coastile for accidents occurred in one of the ATSs.

				Release quantity								
				70 T			**700 T**			**7000T**		
Wind speed [m/s]				***1.5***	***14***	***24***	***1.5***	***14***	***24***	***1.5***	***14***	***24***
EUROPEAN PART	**Time (hour)**	**Tarifa**	**P1**	1	<1	<1	1	<1	<1	<1	<1	<1
			P2	6	2	1	3.5	1.5	<1	2	<1	<1
			P3	7	2	1.5	4.5	2	1	2	<1	<1
			P4	12	4	2.5	7.5	3.5	2.5	4.5	1.5	1.5
		Algésiras	**P1**	4.5	1	<1	2	1	<1	1	<1	<1
			P2	4	1	<1	2	1	<1	1	<1	<1
			P3	4.5	1	<1	2.5	1	<1	1	<1	<1
			P4	6	2	1	3.5	1.5	<1	2	<1	<1
		Gibraltar	**P1**	14.5	5	3	9.5	4	2.5	6	2.5	2
			P2	10	3	2	6.5	2.5	1.5	3.5	1	1
			P3	9.5	3	2	6	2.5	1.5	3.5	1	1
			P4	7	2	1.5	4.5	2	1	2	<1	<1

The oil spill risk assessment is measured considering the cumulative probability, related to the overall simulated scenarios, that the oil slicks reach the coastal POIs in the successive hour time slots after the beginning of the oil spill accident releases.

Figures 57 and 58 represent, respectively, the coastal environmental risk for the selected African and European POIs. Among the selected POIs, Oued Mersa and Dalia represent the first locations to be affected in case of accidents in the Strait of Gibraltar in the first two hours. Besides, the region of Tarifa and Algeciras also appears to be subjected to a relevant risk on the European side.

According to the timing, after 4 hours, Port Tangier Med and the beaches of Oued Mersa and Dalia beach, on the African Mediterranean coast, have the main probability to be hit by an oil slick generated by maritime accidents in the study area. On the European side, the risk probability of oil beaching on the coasts, is growing, respectively, for Algeciras, Tarifa and Gibraltar.

Due to the interaction between the wind flow and the orography of the coast, the Gibraltar strait is very windy. It is exposed mainly to two types of winds (BENALI, 2016; El Gharbaoui, 1981):

- East winds dominate in March and from July to October with a wind speed exceeding 8 m / s is 22% of the day;
- The west winds of Atlantic origin and important source of humidity and precipitation, dominate from December to April (BENALI, 2016; Thauvin, 1991; El Gharbaoui, 1981).

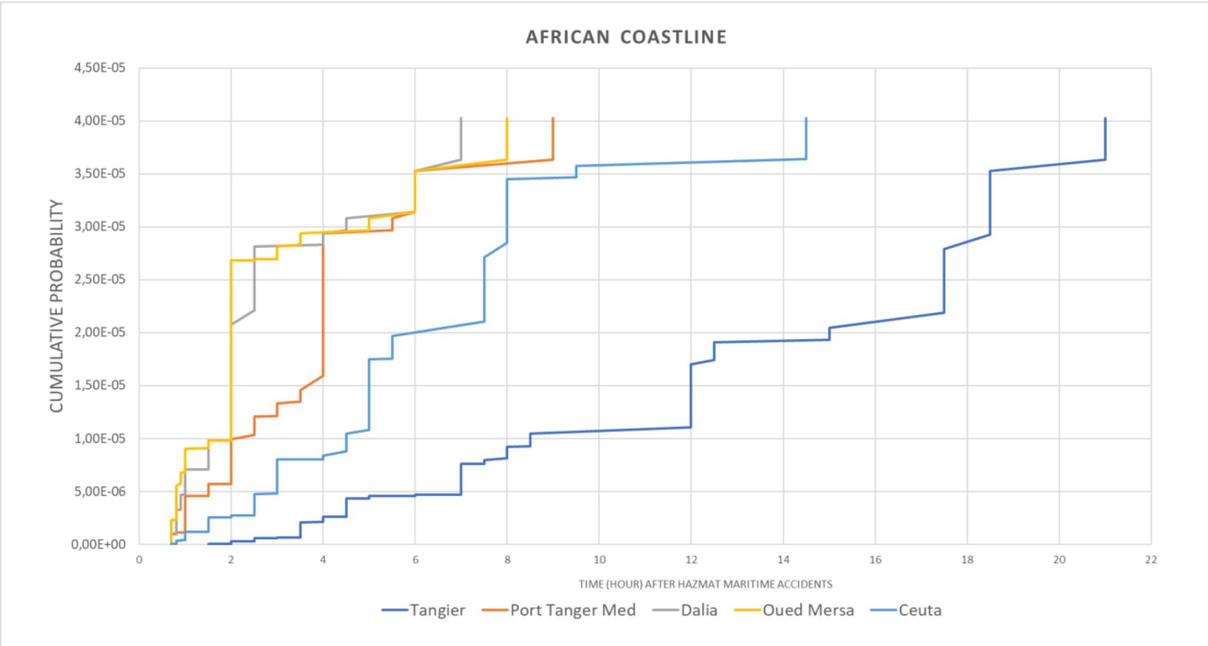


Figure 57: Probability of having a spill accident in the African part (Moroccan coasts)

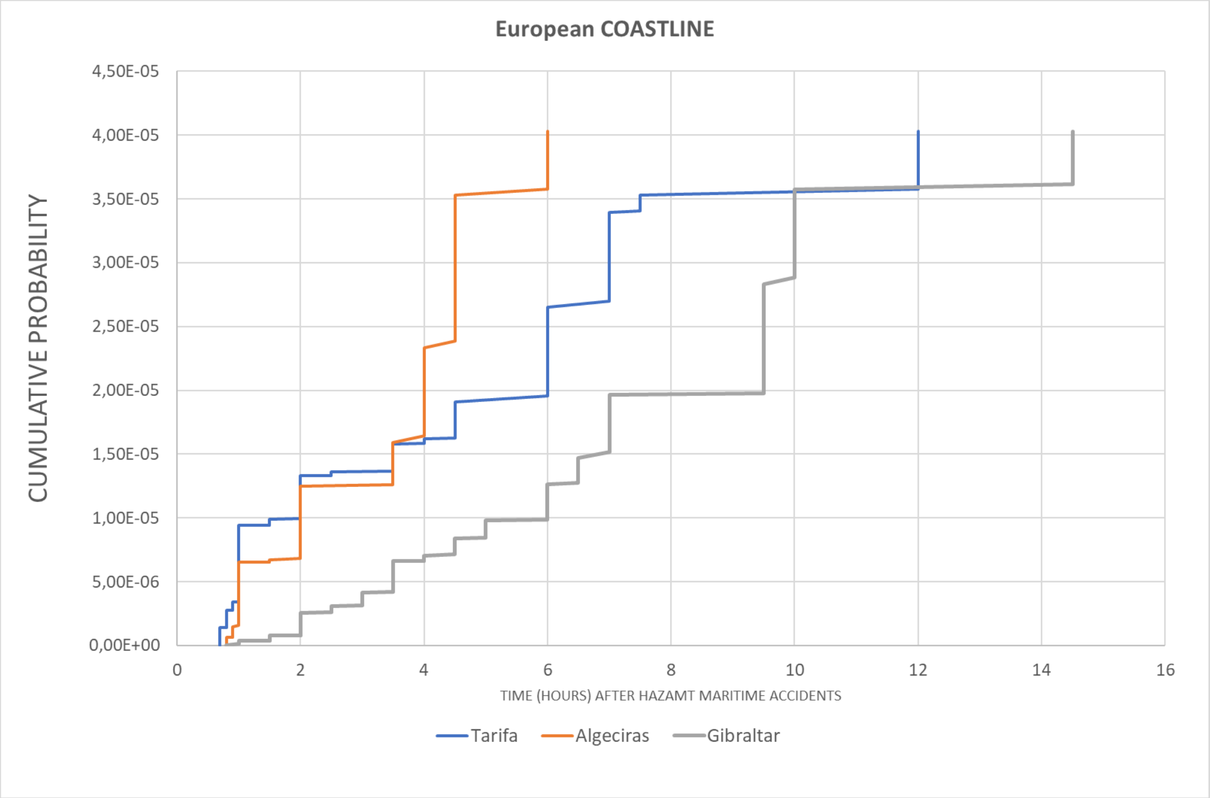


Figure 58: Probability of having a spill accident in the European part (Spanish coasts).

According to information provided by REMRO Network (REMRO Network, 2018) the wind in the test points ATS1 and ATS4 has direction East-South-East and West direction (ESE-W) with a percentage of 53%, directed to European side, and direction West-North-West and East direction (WNW-E) in 47%. On the other hand, for the test points ATS2 and ATS3, the direction of the dominant winds, towards the Moroccan coast, is between WNW-E with a percentage of 61% (39% for ESE-W).

The importance of the proposed model appears to be most obvious due to this wind variability. Thus, it represents an added value in the real time applications in case of maritime accidents.

The intense maritime traffic can be considered as the cause behind the occurrence of several accidents at the main maritime routes with more than 325,000 trips in the Mediterranean Sea in 2007, representing a capacity of 3,800 million tons (REMPEC, 2018): along the main east-west axis connecting the Strait of Gibraltar and the various distribution branches of the eastern Mediterranean, via the Sicilian Channel and the Ionian Sea, and along the roads leading to the main ports of unloading of the coast north of the Adriatic, east of Corsica, also along the Ligurian Sea and around the Gulf of Lion (Ameer et al., 2008).

However, in recent years the typology of maritime accidents has undergone some changes. The number of disasters is declining. In most cases; these incidents result in small spills, yet, permanently, they cause many collisions, groundings and shipwrecks.

We have observed that during the last 40 years (between 1977 and 2017), based on the 980 accidents that occurred and recorded by REMPEC, almost 30% of the incidents (268 accidents) involved oil. Nearly half of the accidents leading to large spills (over 7 tons) reported to REMPEC took place in the eastern Mediterranean (197 accidents, or 74% of accidents involving oil). The rest of the accidents occurred in the western Mediterranean (representing 26% of the total). No accidents were reported at Strait of Gibraltar level.

The eastern part of the Mediterranean is ranked first as an area vulnerable to maritime accidents, more specifically in the region of Greece. The causes of these incidents are numerous:

- The high traffic of the maritime transport of goods;
- The recreational maritime transport which has grown exponentially;
- The Touristic traffic, which has experienced an extraordinary development especially cruise ship;
- Traffic related to sea fishing activity.

This traffic is located in a small part of the sea characterized by the presence of many islands.

Compared to our study area in the Strait of Gibraltar, several factors make it possible to classify it as a zone of low number of accidents compared to other areas of the Mediterranean. Actually, the Strait is a transit route dedicated exclusively to East-West goods and an axis connecting passengers between Morocco and Spain. The Strait is rarely used for tourism and fishing activities.

This reduction in the number of accidents is, in part, attributed to the GIBRALTAR Straits Surveillance and Aid to Maritime Navigation System (Tangier-Tarifa-Gibraltar). This system is dedicated to the surveillance of maritime traffic in the Strait of Gibraltar, where a Vessel Traffic Service (VTS) is located.

It should be noted that most Mediterranean countries have ratified the international conventions dealing with the impact of ships on the environment (MARPOL, AFS, BWM). However, the actual state shows the non-application of international regulations by all operators. Most of these Mediterranean countries have adopted a national emergency plan, and many of them have developed subregional contingency plans, and programs to train staff and the availability of specific equipment, as well as satellite monitoring programs.

Indeed, this model can provide an extensive overvaluation of the spill zone, for the reason that it takes into consideration merely two among the numerous determining factors of the spill movement.

Conclusions

The proposed risk model provides wide-ranging and fast information on the direction, spreading and magnitude of the oil spill, as well as it identifies the coastal areas which may be affected more or less quickly. This approach may be integrated with a GIS tool to generate detailed simulated maps on trajectories and oil slick spreading toward the relevant coasts.

The proposed model has been applied to 288 significant scenarios generated considering four potential accident sites in the West Mediterranean Sea. The accident probability analysis is function of three components related to maritime oil spill accident frequency on the maritime routes included in the study area, probability of spill sizes, and a joint probability function of wind direction and speed. The consequences model related to the prediction of the oil slick trajectories and affected areas takes into consideration the spreading, the advection and the diffusion processes. To determine the oil spill path, data about the weather conditions and surface currents have been utilized.

Risk assessment for the coastal POIs is based on the cumulative probability to be impacted by an oil spill, over the time, starting from the initial accident event.

The main contribution of this chapter is twofold. Firstly, the model application ranks the coastal locations according to higher hazmat risk to be strongly affected by the oil spill in each time intervals. Secondly, the proposed model, connected to adequate ICT equipment to acquire in real time data on weather and sea currents represents a useful tool to manage the immediate containment and recovery activities.

Eventually, the proposed model may underestimate the oil slick impact area since it does not encompass all the possible physical processes in the water column. In the future development of the model, also dispersion, emulsification and dissolution phases may be taken into account.

Chapter V: Risk assessment related to the handling and storage of petroleum products in a fixed site

Introduction

This study about risk assessment is conducted especially for a terminal of storage and distribution of hydrocarbons in the largest port in the North of Africa.

This study in this chapter discusses the potential risks of facilities by describing the main likely accidents, their causes (internal or external), their nature and their consequences. This study includes a description of the facilities and the environment, as well as an analysis of the risks related to the facilities, products handled and the environment of the site. Hazardous phenomena identified during this risk analysis will be simulated in order to quantify their consequences on the facilities of the Establishment and the environment of the latter. It justifies measures to reduce the likelihood and effects of these accidents. It specifies the consistency and the means of internal or external rescue implemented in order to combat the effects of a possible disaster.

This study must allow a rational and objective approach to the risks incurred by people or the environment. Our goal is the contribution made to the main objectives of the administration which are:

- improve the reflection on the security inside the establishment in order to reduce the risks and optimize the prevention policy;
- promote technical dialogue with the inspection authorities to take account of technical and organizational considerations;
- provide, if necessary, constraints in terms of urban planning and land use in the vicinity of the facilities.

The main activity of this terminal is the reception of hydrocarbons, their storage and them redistribution via loading stations trucks and wagons. To achieve this end, the terminal has the following technical data (Figure 59):

- Area of 12 ha;
- Storage capacity of 508 000 m3 distributed in 19 tanks;
- Stored products: Gasoline, gasoline additives (MTBE + Ethanol), Diesel;
- Marine Diesel, fuel oil, heavy fuel oil and additives for fuel oil.

In addition to the tanks, the terminal has the following infrastructures:

- 2 piers 3 km from the terminal receiving vessels of up to 120,000 m3;
- 12 pipes produced in diameter 20 " (4 pipes), 16 " (8 pipes), 12 " (2 pipes) and 8 " (1

pipes);

- 12 " pipe for fire water;
- 6 truck loading station;
- 1 post loading wagons.

The identification of the hazards was made through a careful study of the feedback of experience in similar installations as well as by the examination of the Material Safety Data Sheets (MSDS) of the products which could be present on the site.

The main dangers related to this company have been identified at two levels:

A. Intrinsic hazards related to products: All hydrocarbons present in the establishment are classified as flammable. As already indicated in the 1st chapter, the flammability of a product is defined in particular by its flash point. For example, certain products such as gasoline emit vapors at room temperature, while diesel or heating oil requires a moderate pre-heating to reveal the first flammable vapors.

Regarding the risk of pollution, although intrinsically biodegradable, hydrocarbons when discharged in large quantities are potentially dangerous for the soil or the aquatic environment.

B. Activity Risk Analysais :

This risk analysis covers, in the case of our study, the terminal as well as the pier (loading arms on the pier to the storage bins or loading stations). These facilities were subject to a risk analysis at two levels:

- A preliminary risk analysis to identify major risks,
- A detailed analysis to characterize the critical scenarios more precisely.

It turns out that the risks that an oil depot can pose are two-fold:

- A fire, following a hydrocarbon leak and its ignition,
- An explosion inside a tank, or an ignition of a cloud of gas following a leak and the evaporation of the product (the latter, if necessary, being only possible with gasoline).

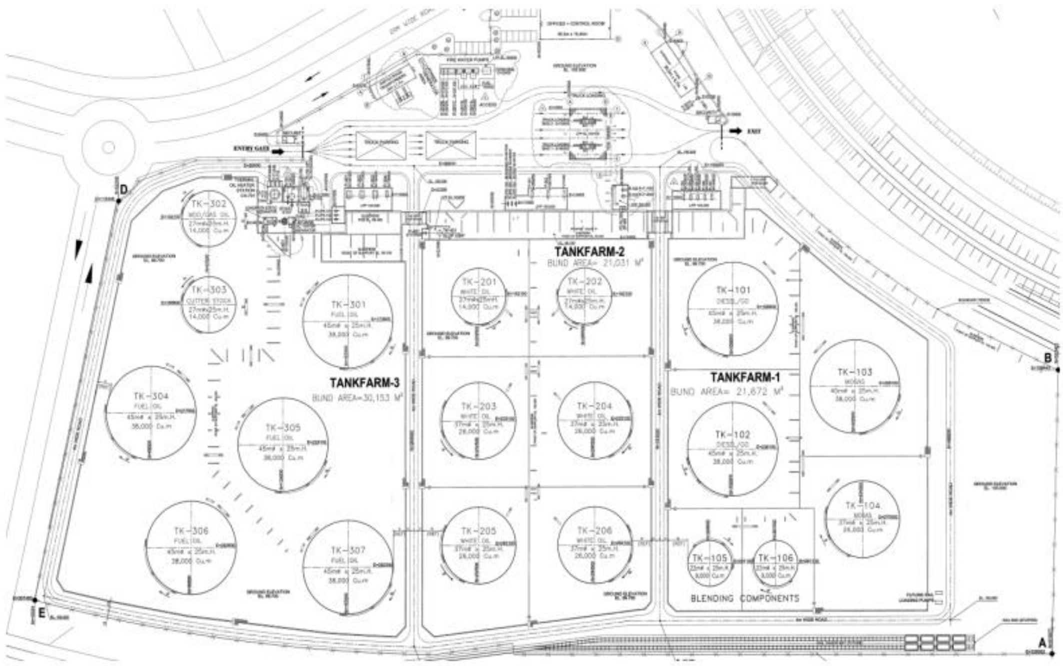


Figure 59: Plan of the three existing tank farms

I. Presentation of the QRA methodology

Quantitative risk assessment (QRA) is deemed to be the advancement of a quantitative estimation of hazards based on engineering assessment and math calculations by mixing estimate of occurrence results and frequencies (Hassan et al., 2009). This means that the QRA not only could present a general hazard evaluation but it also has the ability to show the relational connection between the incident frequency and results.

QRA method, evolved for the Chemical (CCPS, 2008), presents a 3-dimension evaluation in which the axes represent the three main factors that outline the scope of a QRA. A person can perform a restrained, generalized or designated set of danger estimation and, present day, she/he can perform a qualitative, semi-quantitative, or quantitative hazard evaluation. To clarify more, the representation of estimation with the aid of outcome, frequency, and hazard is indicative of the level of maturity of those strategies.

To put it differently, the practical application of those well-known processes to compute hazard assessment gives rise to various problematic issues. The predominant parameters of the QRA concerned in estimating the frequency and the effects of the accident eventualities, for example accident rate, exposure quantification and the release probability.

The only option in this case is to increase a representative model of the risks associated to the system. Since that exists a limitless wide variety of opportunities that risky effects may additionally expand it's far impossible to assess all feasible conditions; therefore, the evaluation is limited to a confined wide variety of selected representative situations. It should constantly keep in mind that threat analysis is a model primarily based on preconditions and assumptions and isn't a replica of truth (Massimo et al., 2013). Nevertheless, threat evaluation provides a much better understanding of threat associated tactics than merely revel in-primarily based ideas.

This is a systemic method to investigate sequences and interrelations in capability incidents or injuries, considering the occasions logic chain, essential dangerous events and undesired consequences. The version makes the quantification of risks establishing the idea of a performance-based totally approach for the evaluation of safety standards.

The solutions of this analysis allow to check the overall consistency of safety making plans, to choose among alternatives layout answers, to demonstrate that safety requirements are fulfilled, Nowadays the protection for humans in many nations is completed on the basis of prescriptive policies:

A prescriptive requirement specifies precise protection capabilities, actions or programmatic factors to be protected within the design of technical device, as the manner for achieving a desired intention. The implementation of these requirements needs to be carried out more or less without thinking about the person traits of a building or commercial manner (Massimo et al., 2013).

The technique of quantitative probabilistic chance evaluation contributes to outline a proactive technique to safety useful to quantify the potential risks overcoming and integrating the based totally method at the learned ideas via accident took place yet.

In the proposed approach, the risk (R) is associated to the expected value of the probability (P) of an accident occurrence of the consequences arising given the occurrence of a hazmat accident. The risk (R) is defined as probability (P) times consequence (C) (CCPS, 2008).

I.1. Frequency analysis

Frequency analysis as indicated in chapter 2 is implies the computation of two main components: the probability that the undesirable Initiating Event (IE) may occur and the probability of hazmat outcome after the IE. The hazard outcome case represents the physical manifestation of the incident scenario i.e. jet-fire, pool fire, or toxic cloud in case of toxic product transportation. The frequency analysis for IE includes the computation of the estimated accident rate (per year) for the specific logistic operation. The task to compute the accident rate requires a large amount of accident data.

In the proposed approach, the accident frequency comes from statistical data of accidents of the breaking occasions of the plant and/or system transfer to be able to deduce the chance of occurrence for the forms of Quantitative Risk Analysis (QRA) and to evaluate the quantitative threat indicators. (Massimo et al., 2013; LEES, 2012).

The reasons of beginning events assumed for the gasoline plant, typically talk over with historical analysis of accidents related to (Massimo et al., 2013):

- The catastrophic ruin of the storage tank;
- The partial destruction of the storage tank;
- The overall destruction of the transfer products pipes;
- The partial destruction of the transfer products pipes;
- The leak from a gasket of the coupling flange.

The table 52 represents the probability of occurrence of the initiating event based on the available databases for the plan of the petroleum products based on worldwide records series from global databases (LEES, 2012).

Table 52: Probability of incidental events occurrence

	Event	**Diameter (mm)**		
		<50	**50-150**	**>150**
Frequency (Occasions/year)	The catastrophic ruin of the storage tank.	3.0E-06		
	The partial destruction of the storage tank;		3.0E-05	
Frequency (Occasions/hours of use)	The overall destruction of the transfer products pipes	1.0E-10	3.0E-11	1.0E-11
	The partial destruction of the transfer products pipes	1.0E-09	6.4E-10	3.0E-11
	The leak from a gasket of the coupling flange	5.0E-08		

With the goal of presenting a technical scientific standardized version relevant for similar contexts, the activities were normalized with respect to appropriate space-time body and that they were standardized with respect to the actual size of the plant. Starting from the initiating activities, we proceeded to the particular reconstruction of individual scenarios by way of the event tree evaluation. This method is based totally at the graphical representation of a logical version which identifies the evolution of incidental speculation. In order to define the outcomes of incidental events, it is far suitable to define the scale of the spillage, which determines the amount of the substance inside the environment. The flow price in the liquid segment turned into calculated by using application of the discharge models, based at the equation of mechanical strength stability (Massimo et al., 2013; BOSCH et al., 2005)

In case of leakage of a liquid product, the pushing force is typically the strain and the stress energy are converted to kinetic power throughout the release. The flow rate of released fluid depends not on the dimensions of the hollow (or the hole from which the leak happens). However, it also occurs due to different elements such as the density of the fluid, the share of the liquid head, the initial and final cost of the spilled fluid, the sum of phrases associated with the weight losses and the speed of leakage of fluid from the hollow. The size of the entire launch is associated with the period of the spill. The duration of the outflow is defined via summing the desired time to come across the leak (alarm time) and the specified time to interfere operatively and to prevent the release.

- **The Event Tree Analysis**

The Event Tree Analysis indicates all capacity evolutionary paths of a starting up event, which range in relation to residual danger associated with the impact of the designed safety capabilities to protect the system. The Events Trees, advanced because the compliant initiating occasions for the plant, are composed of the following analytical steps:

- determination of the initiating event;
- identification of the protection features;
- production of the event tree;
- evaluation and analysis of the effects.

The starting up event, chosen to demonstrate the Event Tree diagram, is the “Catastrophic ruin of the gasoline storage tank” with a twin purpose:

- To display the method by way of which it makes the analysis of the bodily-chemical occasion and the quantification of the probability of prevalence;
- To exhibit the opportunity to perform the risk analysis for the event “Catastrophic destroy of the tank” although it is characterized through incidental eventualities that have a low chance of prevalence.

It is cited that a “catastrophic wreck” it is deemed to be a rupture of massive size, which could cause the leakage of all the product.

The containment basin, current inside the plant, has such dimensions to keep all of the liquid contained in the tank. The tanks are ready with level manipulation system, which allows to check any time the real degree of the liquid. The leakage can be in reality detected and the launched product can be transferred into appropriate volumes of containment. The possibility of the leakage detection has been calculated by means of the usage of the “fault tree” tested in Figure 60.

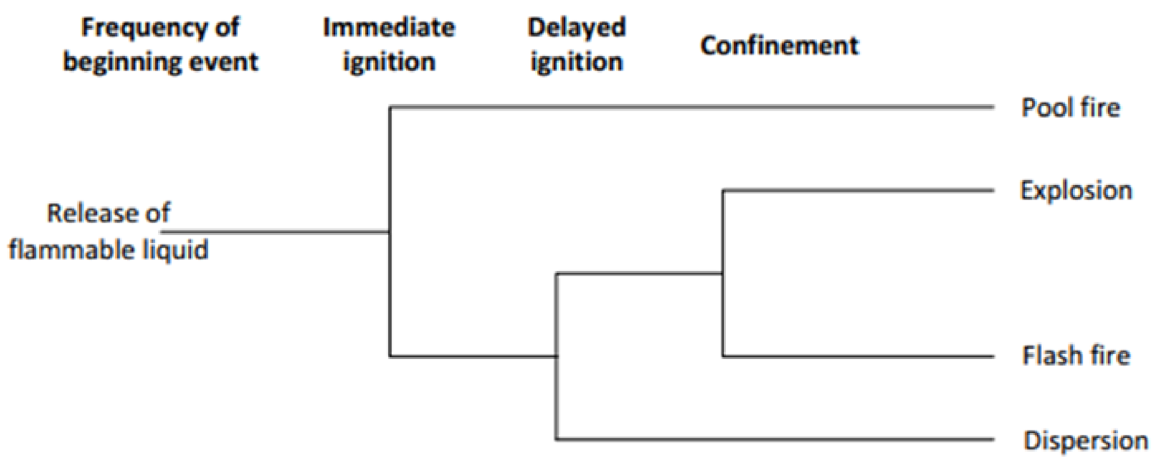


Figure 60: Generic event tree of flammable liquid

I.2. Consequence analysis in the proposed approach

The hazard evaluation, associated with the generated risky events, assumes that, given the characteristics of the substance, it is recognized the complete institution of the initiating event and for each event.

The dangerous outcomes of a chemical incidental event invest with lowering severity the encompassing area, depending on the space from the ignition supply, except if a domino impact occurs.

A fireplace can motive limited direct damage to uncovered character inside the proximity place (radiation, poisonous combustion merchandise).

The explosions, alternatively, have continually consequences in terms of stress wave.

Depending on the explosion length, effects related to the splinters and on the improvement of warmth and combustion products may also arise.

For the representation of the harm regions, concerned by way of the prevalence of the incidental scenarios, reference became made to the related threshold values in Italian Ministerial Decree May 9th, 2001 "Pianificazione del territorio e rischio tecnologico" (Italian Ministerial, 2001). Minimum safety requirements referring to city and territorial planning for the affected areas with the aid of the fundamental coincidence hazard plants- (Table 53).

Table 53: Threshold values of reference

FIRE (Steady thermal radiation)	**12,5 kW/m^2**	**7 kW/m^2**	**5 kW/m^2**	**3 kW/m^2**	**12,5 kW/m^2**
BLEVE/Fireball (Variable thermal radiation)	Raggio del fireball	350 kJ/m^2	200 kJ/m^2	125 kJ/m^2	200/800 m
Flash-fire (Snapshot thermal radiation)	LFL	½ LFL	-	-	-
VCE-UVCE (Peak overpressure)	0.3 bar (0,6 bar spazi aperti)	0.14 bar	0.07 bar	0.03 bar	0.3 bar
Toxic release	LC50 (30 min, hmn)	-	IDHL		

(source: Italian Ministerial Decree May 9th, 2001)

The carried-out simulations to quantify the threat of described incidental situations through the Event Tree, represent substantial situations of dispersion, of spills and consequent propagation of the pool with feasible immediately cause of the product (Pool-Fire) or behind schedule trigger of flammable vapor cloud (Flash Fire) or explosion of Unconfined Vapor Cloud (UVCE).

The incidental eventualities, because of the discharge into the surroundings and the subsequent ignition of gasoline, are:

- Pool-Fire: trigger of a launched liquid substance in restricted area or not This event normally produces the hearth of the ‘pool’ from which it can derive a radiation phenomenon and smoke emission. The effects are related to the radiant heat that hits the target. The threshold values are expressed as thermal energy incident for unit of exposed surface (kW/m^2);
- Flash-Fire: bodily phenomenon attributable to the not on time ignition of a flammable vapors cloud produced through the leakage substance.

The flash fire has a wonderful heat flux in a short time interval, generally much less than three sec. Occasional events of lethality can concomitantly occur with any isolated pockets and local flame, probably also gift over the decrease flammability restriction, due to possible nonhomogeneity of the cloud.

In the case of formation of a flammable liquid pool that doesn’t locate immediately ignition, the liquid vaporizes from the puddle and creates a flammable cloud. The consequences of reason of the flammable substance cloud (gas or vapor) are represented through the immediately thermal radiation.

The flammable cloud is the entire region wherein the attention of the flammable-air combination is above the lower flammability restrict. The flammable cloud is a part of the air-flammable combination at recognition above the decrease flammability restrict or at half of that rate.

Unconfined Vapor Cloud Explosion (UVCE): not restrained launch within the surroundings to a flammable substance within the gas phase or vapor from variables effects of temperature and overpressure.

The threshold price for extended deadly effects, refers on the indirect lethality because of falls, throws the frame of limitations, influences of splinters and particularly disintegrate of buildings (0.3 bar), whilst, in unconfined regions (without homes or different vulnerable structures) it can be suitable to recall simplest the direct lethality, generated by the shock waves such (0.6 bar).

The limit cost for irreversible and reversible accidents are basically associated with the distance to which the projection of splinters, even light, generated by the surprise wave are anticipated. With regard to the domino effect, the threshold rate (0.3 bar) emerge as fixed consistent with commonplace distance of the splinters projection that might purpose harm at tanks, gadget, piping.

II. Case study: application of the proposed methodology on oil Terminal

The proposed case study consists of defining the risks for hazmat storage incurred by people or the environment in oil terminal - Morocco

The main activity of this terminal is the reception of hydrocarbons, their storage and them redistribution via loading stations trucks and wagons. To achieve this end, the terminal has the following technical data (Figure 59):

- Area of 12 ha;
- Storage capacity of 508,000 m3 distributed in 19 tanks;
- Stored products: Gasoline, gasoline additives (MTBE + Ethanol), Diesel;
- Marine Diesel, fuel oil, heavy fuel oil and additives for fuel oil.

In addition to the Gasoline tanks, the terminal has the following infrastructures:

Table 54: Gasoline tank infrastructure

Pipe diameter (inches)	Length of the Line (m)	N° Flanges	N° Tanks	Operating Time (hours /year)
16	2700	37	3	8472

II.1. Frequency analysis for the case study

The value of probability to be attributed to the different types of ignition was obtained by the release rate as indicated in following table:

Table 55: The occurrence frequency of the initiating events of the analyzed plant

	Event	Frequency	Frequency of occurrence (occasions/year)
Frequency (Occasions/year)	The catastrophic ruin of the storage tank.	3.00E-06	9.00E-06
	The partial destruction of the storage tank;	3.00E-05	9.00E-05
Frequency (Occasions/hours of use))	The overall destruction of the transfer products pipes	1.00E-11	2.29E-04
	The partial destruction of the transfer products pipes	3.00E-11	6.86E-04
	The leak from a gasket of the coupling flange	5.00E-08	1.57E-02

From where it is concluded that the leakage detection and the resultant drainage can happen only if the leakage can be detected by the responsible who is in charge of the control phase and supervision or if concurrently the proper functioning of the extent indicator and the operator of the remote control detects the leakage arise.

The probability of the release detection, obtained by the Fault Tree Analysis, is 9.21E-01 while the complementary probability that represents the not detection of the spillage is 7.90E-02.

The figures 61 to 65 shows the event Tree Analysis for the scenarios studied:

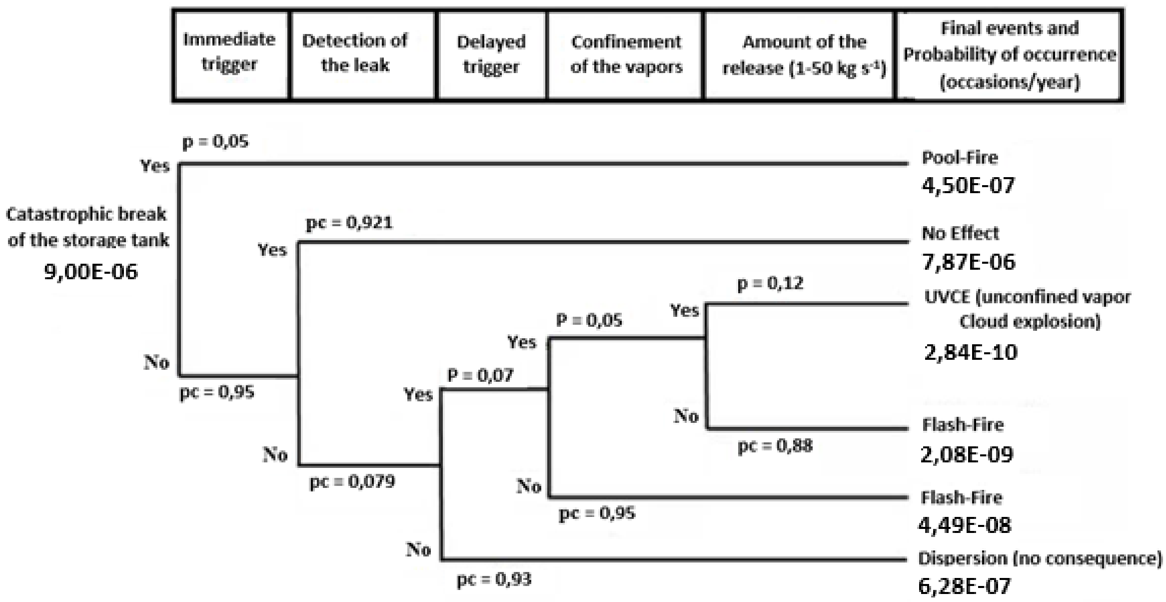


Figure 61: Event Tree Analysis- The catastrophic ruin of the storage tank.

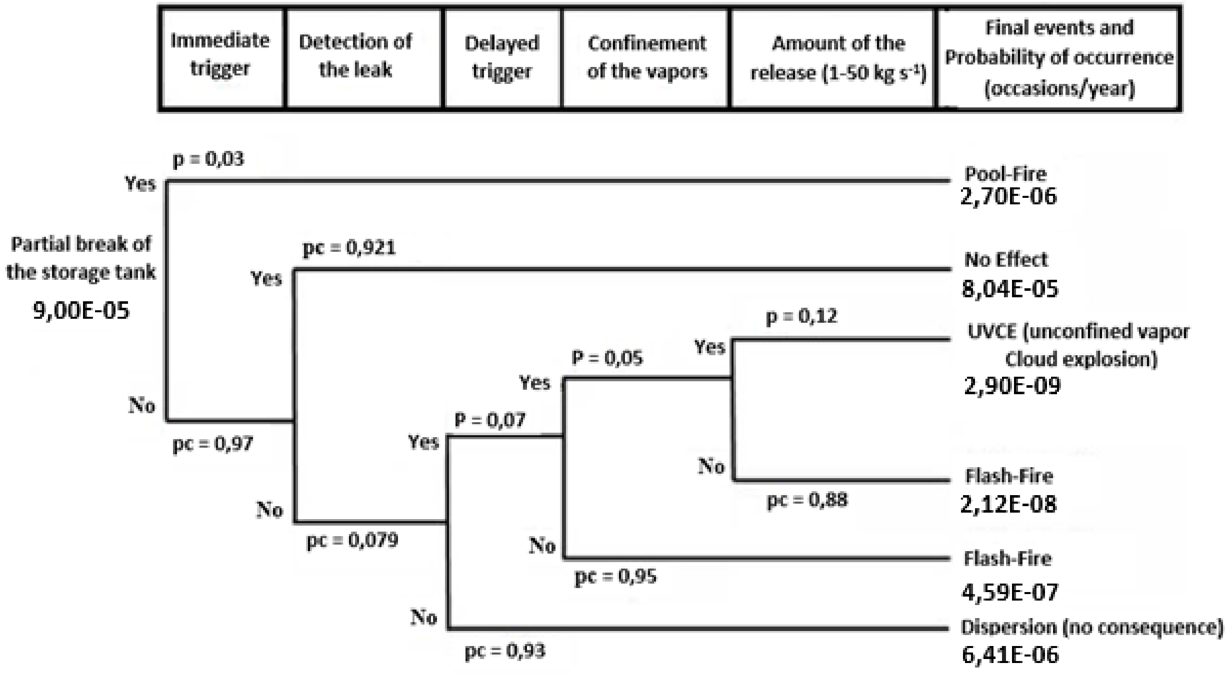


Figure 62: Event Tree Analysis- The partial destruction of the storage tank;

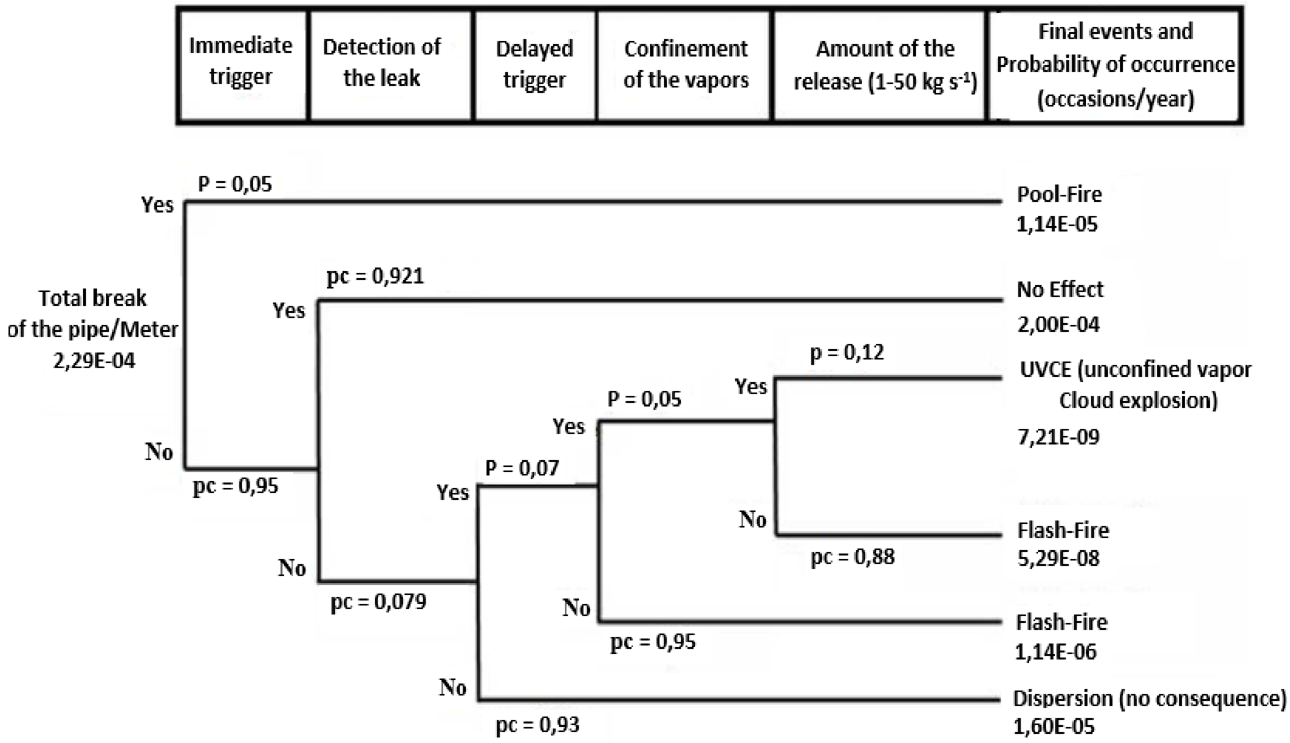


Figure 63: Event Tree Analysis- The overall destruction of the transfer products pipes (Diameter of the pipe 16")

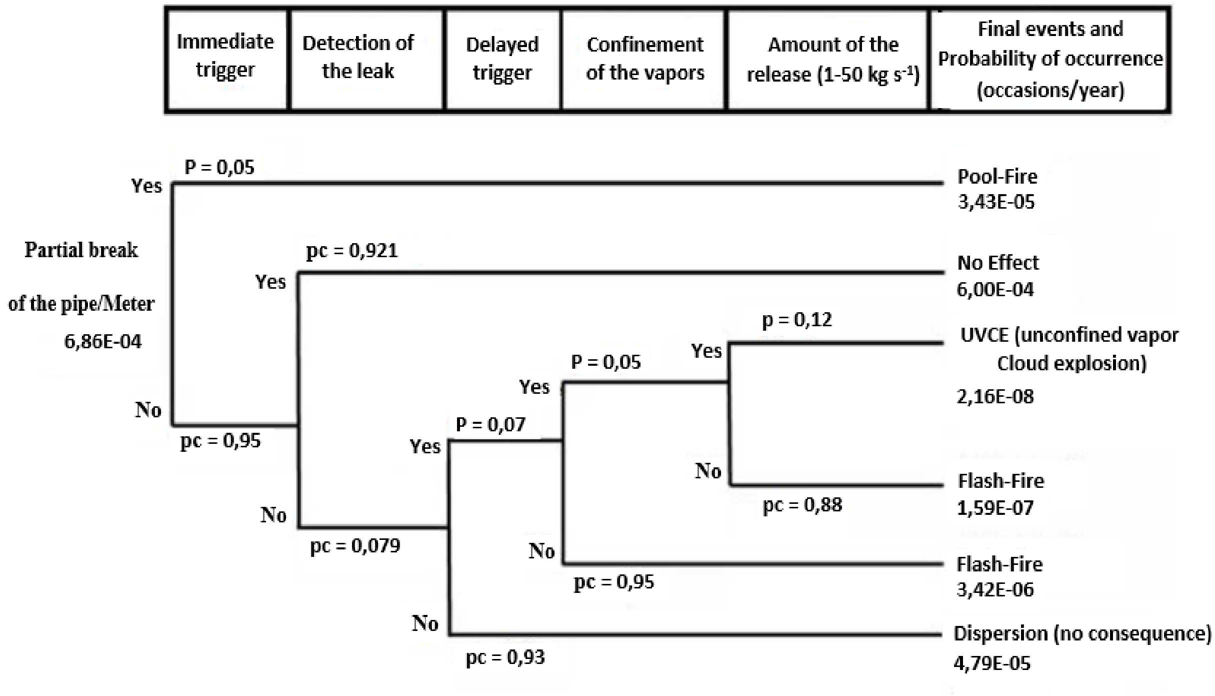


Figure 64: Event Tree Analysis- The partial destruction of the transfer products pipes (Diameter of the pipe 16")

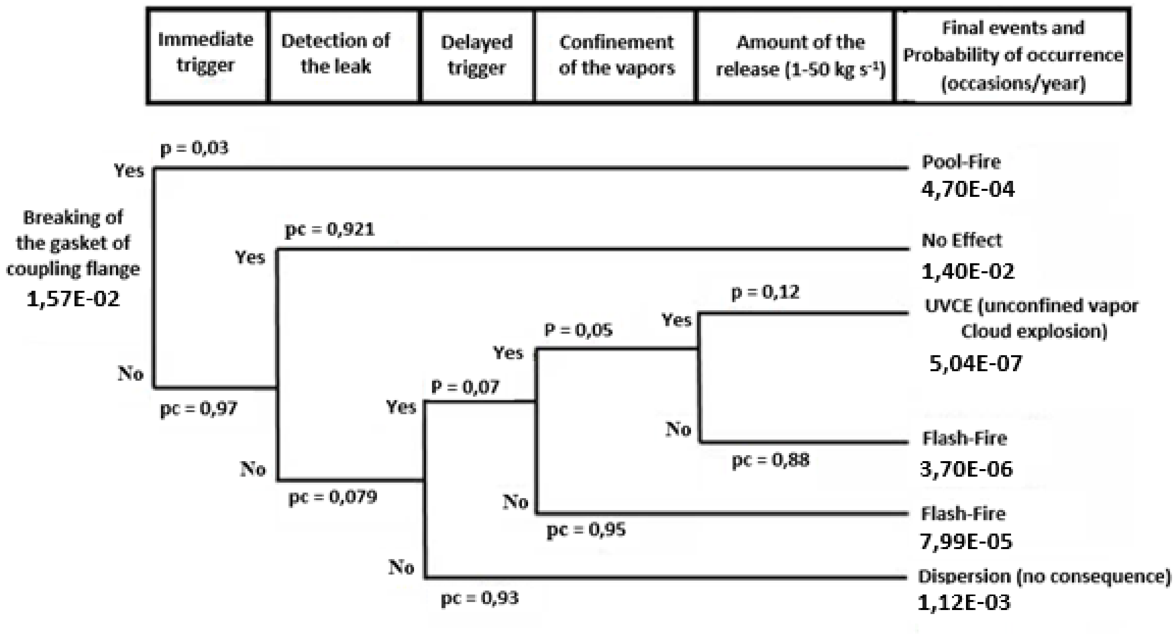


Figure 65: Event Tree Analysis- The leak from a gasket of the coupling flange.

If all the systems failed, the consequent scenarios would be:

- Pool-Fire: immediate trigger and burning of the pool;
- Flash-Fire: delayed trigger of a cloud of flammable vapors;
- UVCE (Unconfined Vapor Cloud Explosion): delayed trigger with vapor cloud explosion;

The occurrence probability of the complete group of incidental scenarios, compatible with the initiating events, are reported in the following table:

Table 56: Probability of occurrence of the incident scenarios

Event	Diameter of the Pipe (inches)	Frequency of Occurrence (occasions/year)	Intervention Time(s)	Probability of the Immediate Trigger: Pool-Fire	Probability of the Immediate Trigger: pool of a cloud of gas	Probability of the Immediate Trigger: UVCE/ /Flash-Fire	Incidental Scenarios	Probability of Occurrence of the Incidental Scenarios (occasions/year)
The catastrophic ruin of the storage tank.	---	9.00E-06	900	0.05	0.07	0.12	Pool-Fire	4.50E-07
							No Effect	7.87E-06
							UVCE	2.84E-10
							Flash-Fire	4.49E-08
							Dispersion	6.28E-07
The partial destruction of the storage tank;	---	9.00E-05	900	0.03	0.07	0.12	Pool-Fire	2.70E-06
							No Effect	8.04E-05
							UVCE	2.90E-09
							Flash-Fire	4.59E-07
							Dispersion	6.41E-06
The overall destruction of the transfer products pipes	16	2.29E-04	60	0.05	0.07	0.1	Pool-Fire	1.14E-05
							No Effect	2.00E-04
							UVCE	7.21E-09
							Flash-Fire	1.14E-06
							Dispersion	1.60E-05
The partial destruction of the transfer products pipes	16	6.86E-04	180	0.05	0.07	0.12	Pool-Fire	3.43E-05
							No Effect	6.00E-04
							UVCE	2.16E-08
							Flash-Fire	3.42E-06
							Dispersion	4.79E-05
The leak from a gasket of the coupling flange	16	1.57E-02	60	0.03	0.07	0.12	Pool-Fire	4.70E-04
							No Effect	1.40E-02
							UVCE	5.04E-07
							Flash-Fire	7.99E-05
							Dispersion	1.12E-03

III.2. Consequence analysis for the case study

After having identified the eventualities that may arise from the incidental occasion, we proceeded to quantify the areas of capability harm with a purpose to symbolize the risks degree of the system. The length of the predicted ability harm regions from the evolution of incidental scenarios was quantified the usage of this machine Aerial Locations of Hazardous Atmospheres (ALOHA), which has allowed us to define the vulnerability of the territory.

The Areal Locations of Hazardous Atmospheres (ALOHA) device has been implemented to generate effect place of a coincidence on street related to fuel product. The information required to model the accident outcome case with Aloha software program seem in the Table that follows:

Table 57: Data required by aloha to simulate hazmat scenario for the case study associate to Gasoline

CLASS Of DATA	TYPE OF DATA	VALUES
SITE DATA	Location :	HTT SA TANGIER Med, MOROCCO
	Building Air Exchanges Per Hour:	0.50 (enclosed office)
	Time:	July 24, 2017 1258 hours ST (user specified)
CHEMICAL DATA	Chemical Name:	**Gasoline**
	ERPG-1	200 ppm
	ERPG -2	1000 ppm
	ERPG -3	4000 ppm
	IDLH	5 mg/m3
	LEL	14000 ppm
	UEL	74000 ppm
	Ambient Boiling Point:	125.4 C
ATMOSFERIC DATA (Manual Input of Data)	Wind / Stability	Scenario I: 1.5 m/s (from EST) / (F: Moderately stable conditions)
		Scenario II: 14 m/s (from EST) / (D: Neutral conditions)
	Ground Roughness:	open country
	Cloud Cover :	5 tenths
	Air Temperature (C)	Scenario I: Average minimum temperature: 13
		Scenario II: Average minimum temperature: 21
	Relative Humidity :	70%
SOURCE STRENGTH	Description :	Tank contains liquid Leak from hole in horizontal cylindrical tank Flammable chemical escaping from tank (not burning)
	Tank Volume :	Tank is 98% full

The different scenarios have been simulated in ALOHA considering two different weather atmospheric conditions (F and D) and for two kinds of wind speed (1.5 and 14 m/sec).

The different distances for different scenarios obtained represented in the following tables. The figures 66 & 67 represent an example of the hazard zones for the different scenarios for the catastrophic ruin of the storage tank computed by Aloha (the others scenarios are attached in Appendix 3).

Table 58: Pool Fire thermal radiation Threat zone distance from the release source expressed in meters.

Event	**Stability / Wind Speed**	**POOL-FIRE Distance from the release source (In the wind direction) (m)**			
		12.5 kW/m2	**7 kW/m2**	**5 kW/m2**	**3 kW/m2**
The catastrophic ruin of the storage tank.	F : 1.5m/s	196	261	307	392
	D : 14m/s	219	275	315	388
The partial destruction of the storage tank;	F : 1.5m/s	39	54	65	84
	D : 14m/s	51	62	70	84
The overall destruction of the transfer products pipes	F : 1.5m/s	120	162	191	244
	D : 14m/s	139	173	197	242
The partial destruction of the transfer products pipes	F : 1.5m/s	25	35	45	56
	D : 14m/s	35	42	47	56
The leak from a gasket of the coupling flange	F : 1.5m/s	25	29	33	39
	D : 14m/s	16	24	29	38

Table 59: Flammable Threat zone distance from the release source expressed in meters.

Event	Stability / Wind Speed	FLASH-FIRE Distance	
		LEL	½ LEL
The catastrophic ruin of the storage tank.	F : 1.5m/s	76	103
	D : 14m/s	85	100
The partial destruction of the storage tank;	F : 1.5m/s	23	33
	D : 14m/s	27	44
The overall destruction of the transfer products pipes	F : 1.5m/s	84	110
	D : 14m/s	99	129
The partial destruction of the transfer products pipes	F : 1.5m/s	<10	12
	D : 14m/s	17	29
The leak from a gasket of the coupling flange	F : 1.5m/s	<10	<10
	D : 14m/s	12	20

Table 60: UVCE Distance from the release source (in meters)

Event	Diameter of the Pipe (Inches)	Stability / Wind Speed	UVCE Distance from the release source (In the Wind direction) (m)		
			0,3	0,14	0,07
The catastrophic ruin of the storage tank.	----	F : 1.5m/s	74	88	127
		D : 14m/s	78	93	123
The partial destruction of the storage tank;	----	F : 1.5m/s	20	29	44
		D : 14m/s	27	39	62
The overall destruction of the transfer products pipes	16	F : 1.5m/s	51	71	104
		D : 14m/s	50	61	86
The partial destruction of the transfer products pipes	16	F : 1.5m/s	<10	<10	15
		D : 14m/s	17	26	40
The leak from a gasket of the coupling flange	16	F : 1.5m/s	<10	<10	11
		D : 14m/s	11	17	27

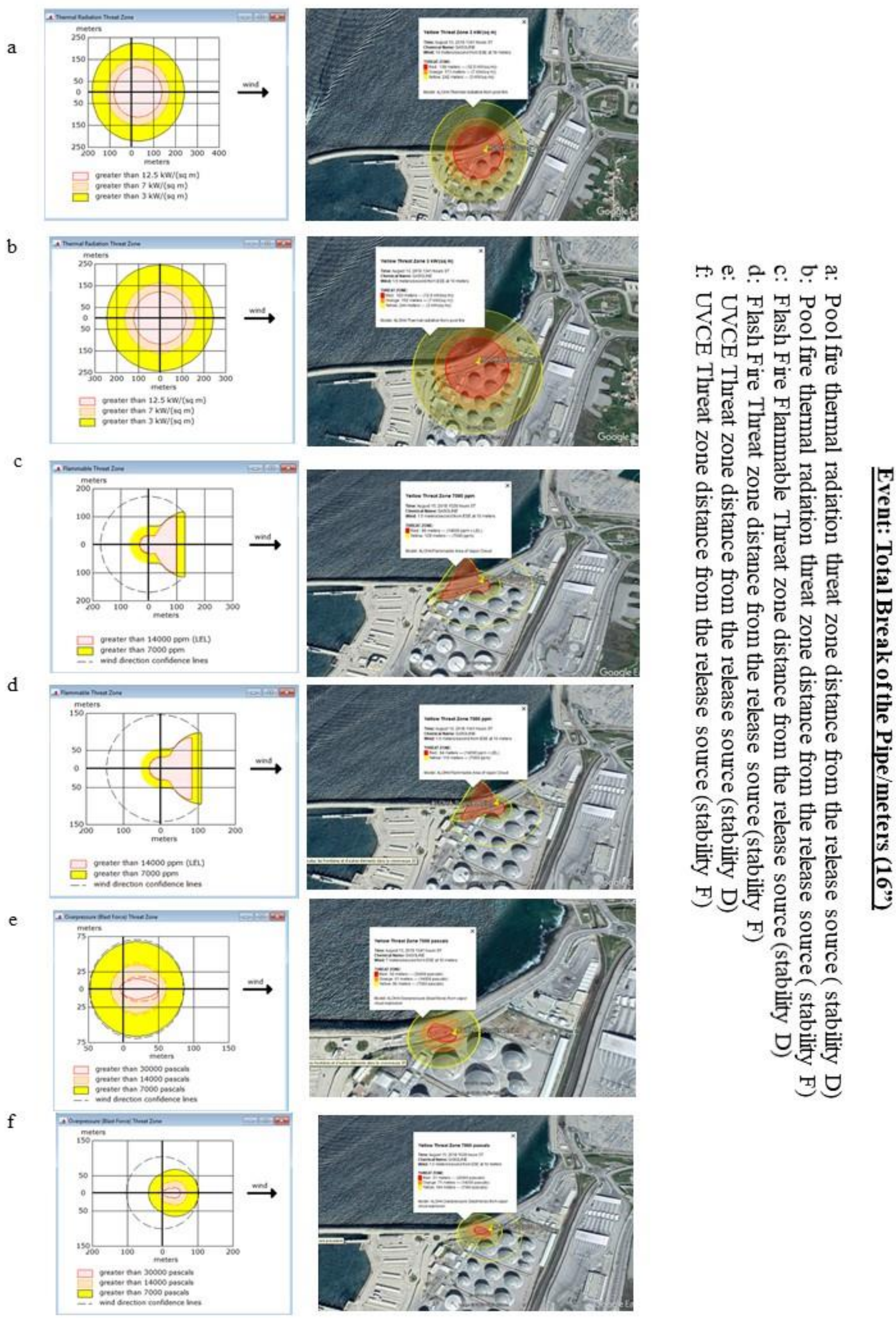
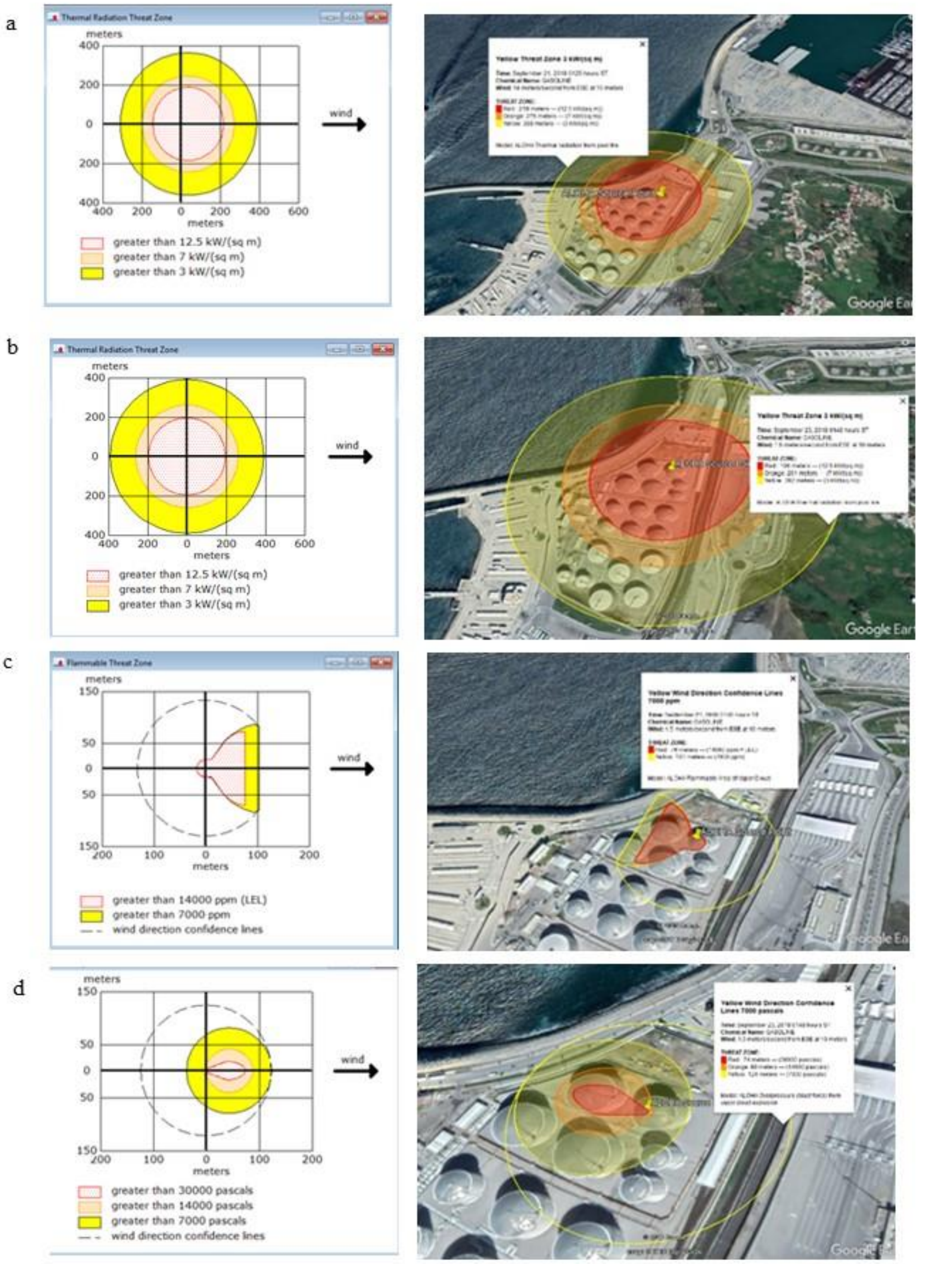


Figure 66 Hazard zones for the different scenarios for the catastrophic ruin of the storage tank. computed by Aloha



Event: Total break of the storage tank

a: Pool fire thermal radiation threat zone distance from the release source (stability D)

b: Pool fire thermal radiation threat zone distance from the release source (stability F)

c: Flash fire flammable hreat zone distance from the release source (stability F)

d: UVCE Threat zone distance from the release source (stability F)

Figure 67: hazard zones for the different scenarios for the catastrophic ruin of the storage tank computed by Aloha

II.2. QRA application

The probability of the incidental scenarios and the evaluation of the potential damage areas allow to define the hazard level of the system.

For comparative analysis has been assumed an evenly distributed and constant crowding of the damage areas, equal to 0.01 exposed/m2 (Massimo et al., 2013).

The damage areas extension and the expected value of the damage (fatalities and injuries) for different scenarios are summarized in Table following (61 to 63).

The results of this study are specific to the company.

Table 61: Consequences of pool fire scenario of each events

Event	Stability / Wind Speed	Fatalities Area (m2)	Injuries Area (m2)	Probability of occurrence of Pool-Fire (events/year)	N° Exposed people	N° Fatalities	N° Injuries	Expected value of damage	
								Fatalities/year	Injuries/year
catastrophic break of the storage tank	F: 1.5m/s	68121	153664	4.50E-07	2218	681	1537	3.07E-04	6.91E-04
	D: 14m/s	87025	150544		2376	870	1505	3.92E-04	6.77E-04
Partial break of the storage tank	F: 1.5m/s	2916	7056	2.70E-06	100	29	71	7.87E-05	1.91E-04
	D: 14m/s	3844	7056		109	38	71	1.04E-04	1.91E-04
Total break of the pipe /Mete (75mm)	F: 1.5m/s	26244	59536	1.14E-05	858	262	595	2.99E-03	6.79E-03
	D: 14m/s	29929	58564		885	299	586	3.41E-03	6.68E-03
Partial break of the pipe /Mete (75mm)	F: 1.5m/s	1225	3136	3.43E-05	44	12	31	4.20E-04	1.08E-03
	D: 14m/s	1764	3136		49	18	31	6.05E-04	1.08E-03
Breaking of the gasket of coupling flange	F: 1.5m/s	841	1521	4.70E-04	24	8	15	3.95E-03	7.15E-03
	D: 14m/s	576	1444		20	6	14	2.71E-03	6.79E-03

Table 62: Consequences of Flash fire scenario of each events

Event	Stability / Wind Speed	Fatalities Area (m2)	Injuries Area (m2)	Probability of occurrence of Pool-Fire (events/year)	N° Exposed people	N° Fatalities	N° Injuries	Expected value of damage	
								Fatalities/year	Injuries/year
catastrophic break of the storage tank	F: 1.5m/s	5776	10609	4.49E-08	1639	578	1061	2.59E-05	4.76E-05
	D: 14m/s	7225	10000		1723	723	1000	3.24E-05	4.49E-05
Partial break of the storage tank	F: 1.5m/s	529	1089	4.59E-07	162	53	109	2.43E-05	5.00E-05
	D: 14m/s	729	1936		267	73	194	3.35E-05	8.89E-05
Total break of the pipe /Mete (75mm)	F: 1.5m/s	7056	12100	1.14E-06	1916	706	1210	8.04E-04	1.38E-03
	D: 14m/s	9801	16641		2644	980	1664	1.12E-03	1.90E-03
Partial break of the pipe /Mete (75mm)	F: 1.5m/s	100	144	3.42E-06	24	10	14	3.42E-05	4.92E-05
	D: 14m/s	289	841		113	29	84	9.88E-05	2.88E-04
Breaking of the gasket of coupling flange	F: 1.5m/s	100	100	7.99E-05	20	10	10	7.99E-04	7.99E-04
	D: 14m/s	144	400		54	14	40	1.15E-03	3.20E-03

Table 63: Consequences of UVCE scenario of each events

Event	Stability / Wind Speed	Fatalities Area (m2)	Injuries Area (m2)	Probability of occurrence of Pool-Fire (events/year)	N° Exposed people	N° Fatalities	N° Injuries	Expected value of damage	
								Fatalities/year	Injuries/year
catastrophic break of the storage tank	F: 1.5m/s	7744	16129	2.84E-10	2387	774	1613	2.20E-07	4.58E-07
	D: 14m/s	8649	15129		2378	865	1513	2.46E-07	4.30E-07
Partial break of the storage tank	F: 1.5m/s	841	1936	2.90E-09	278	84	194	2.44E-07	5.61E-07
	D: 14m/s	1521	3844		537	152	384	4.41E-07	1.11E-06
Total break of the pipe /Mete (75mm)	F: 1.5m/s	5041	10816	7.21E-09	1586	504	1082	3.63E-06	7.80E-06
	D: 14m/s	3721	7396		1112	372	740	2.68E-06	5.33E-06
Partial break of the pipe /Mete (75mm)	F: 1.5m/s	100	225	2.16E-08	33	10	23	2.16E-07	4.86E-07
	D: 14m/s	676	1600		228	68	160	1.46E-06	3.46E-06
Breaking of the gasket of coupling flange	F: 1.5m/s	100	121	5.04E-07	22	10	12	5.04E-06	6.10E-06
	D: 14m/s	289	729		102	29	73	1.46E-05	3.67E-05

Conclusion

This proposed method yielded similar results with the study of risks carried out by the company. where we take for example the scenario of "The overall destruction of the transfer products pipes " which classified according to the matrix of criticality used by the company, like a scenario of disastrous gravity.

The company masters a lot of measures in terms of safety and prevention, for example the traffic plan at the terminal and the prevention of mechanical shocks, as well as the verification of the effectiveness of anti-explosion ripe and thermal screens with respect to this scenario and their upgrading if necessary.

The proposed approach could improve the safety of a hazardous materials storage facility by minimizing worker and population exposure by optimizing hazardous materials planning. Petroleum terminals could apply this methodology to define the risks in the facility for the purpose of making decisions regarding the implementation of risk reduction measures.

Conclusion and perspectives

The aim of this thesis is to propose a systemic approach to risk assessment, taking into account in a global way the risks related to hazardous materials throughout different modality.

In this context, the first issue addressed in this thesis is to assess the level of risk of hazardous goods transport areas for both road and marine modes of transportation, while the second issue of assessing risks in an industrial facility fixed.

In order to determinate the problems in the Moroccan logistic system related to hazardous materials, which we have chosen as a case study, to apply different approaches proposed, we conducted a survey involving several companies used, transport or storage these materials.

The exploratory research we have conducted can pave the way for a wide variety of development perspectives. Among other things, the possibility of developing a guide to good practices for carriers to inform them of the practices they can put in place to reduce their risk, or the possibility of making many recommendations to different ministries in relation to the training, the use of equipment, accident register policies, or even mount communication campaigns to raise awareness of the risks of multi-client carriers and multiple loading / unloading operations.

The proposed approach could improve the hazmat road transport safety minimizing the population exposure by optimizing the scheduling of hazmat vehicle shipments in the planning phase. Hazmat operators could apply this methodology to define the routes at minimum risk. On the other hand, the possibility to evaluate FN curves according to risk acceptance criteria might provide basis for decisions on the implementation of risk-reducing measures.

In the industrial context, the utility of the adoption of QRA decision tool for risk management is often underestimated. QRA could provide informed assessment of cost risk exposures with special relevance in the hazmat transportation context. Besides, it is able to offer significant data to define mitigation risk strategies.

The use of the proposed basic approach allows the user to carry out a speed QRA obtaining still significant risk values. In a real-time or operational decisional level framework, reliable data about risk, even if approximated, could be very suitable to identify immediately the value of risk for a hazmat accidental event.

Anyway, at tactical and strategical decisional level, QRA for hazmat transport deserves to be analyzed with more detailed multi-criteria models, enabling a deeper analysis of the problem. This simple approach can be applied and disseminated throughout Morocco for risk mapping in various regions concerning HM. This helps in making the decision for the authorities as well as the response teams in case of an incident.

On the other hand, the proposed maritime risk model provides wide-ranging and fast information on the direction, spreading and magnitude of the oil spill, as well as identifies the coastal areas which may be affected more or less quickly through to generate detailed simulated maps on trajectories and oil slick spreading toward the relevant coasts. This approach may represent a useful tool to manage immediate containment and recovery activities.

The applicability of the method to another study area is quite satisfactory. In the future development of the model, also evaporation, dispersion, emulsification and dissolution phases may be taken into account.

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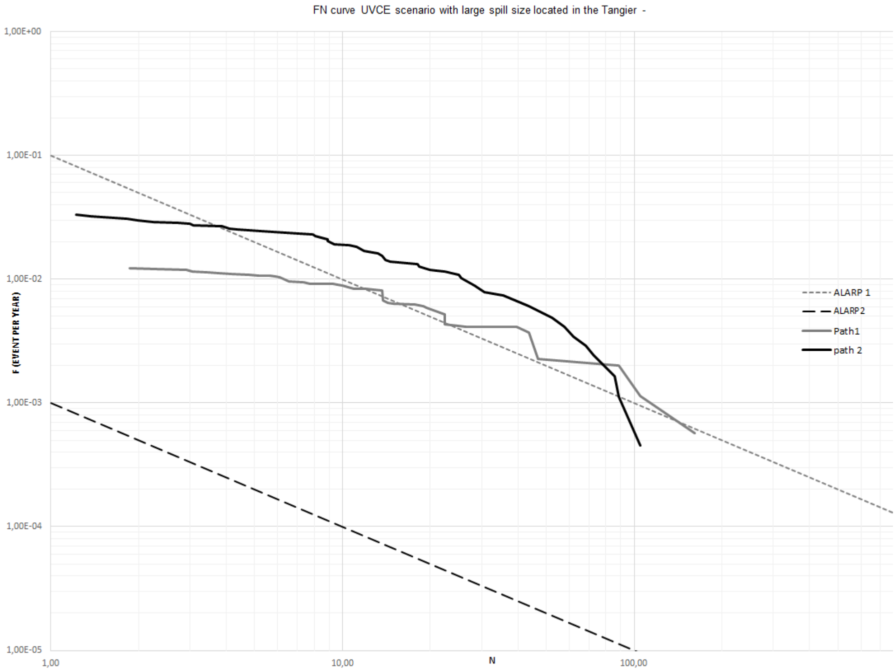
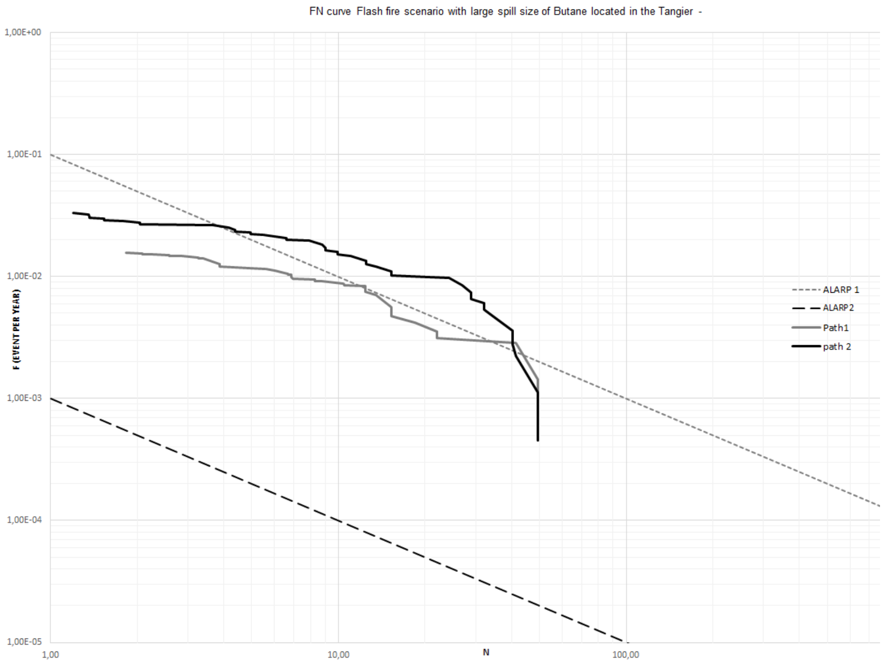
Appendix 1

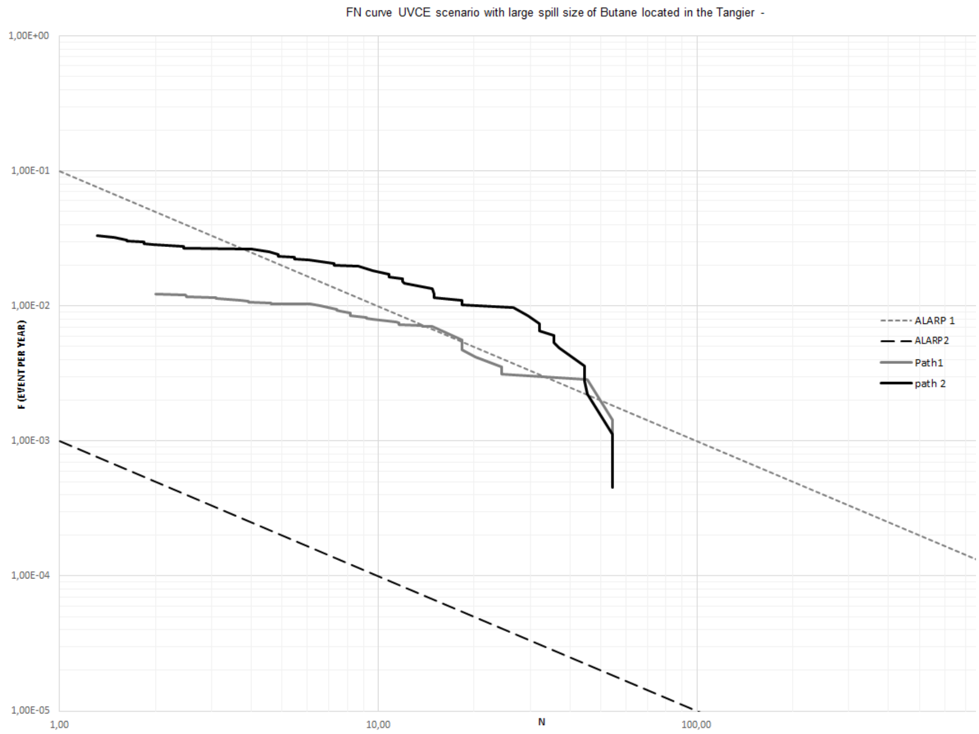
The FN curves have been calculated for the different scenarios studied



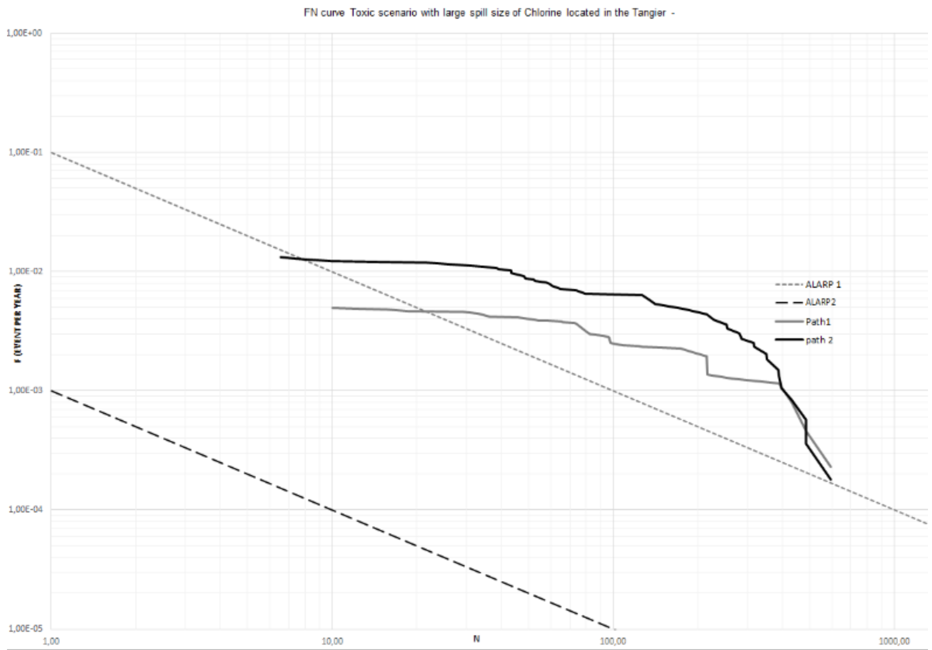
UVCE scenario with large spill size of Gasoline located in the Tangier



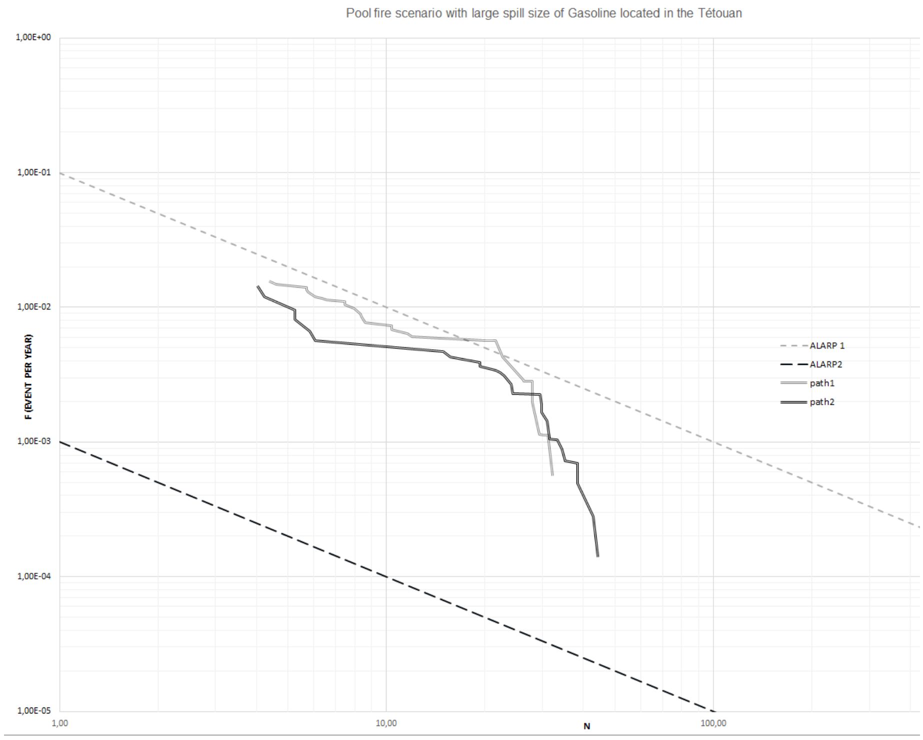
Flash fire scenario with large spill size of Butane located in the Tangier.



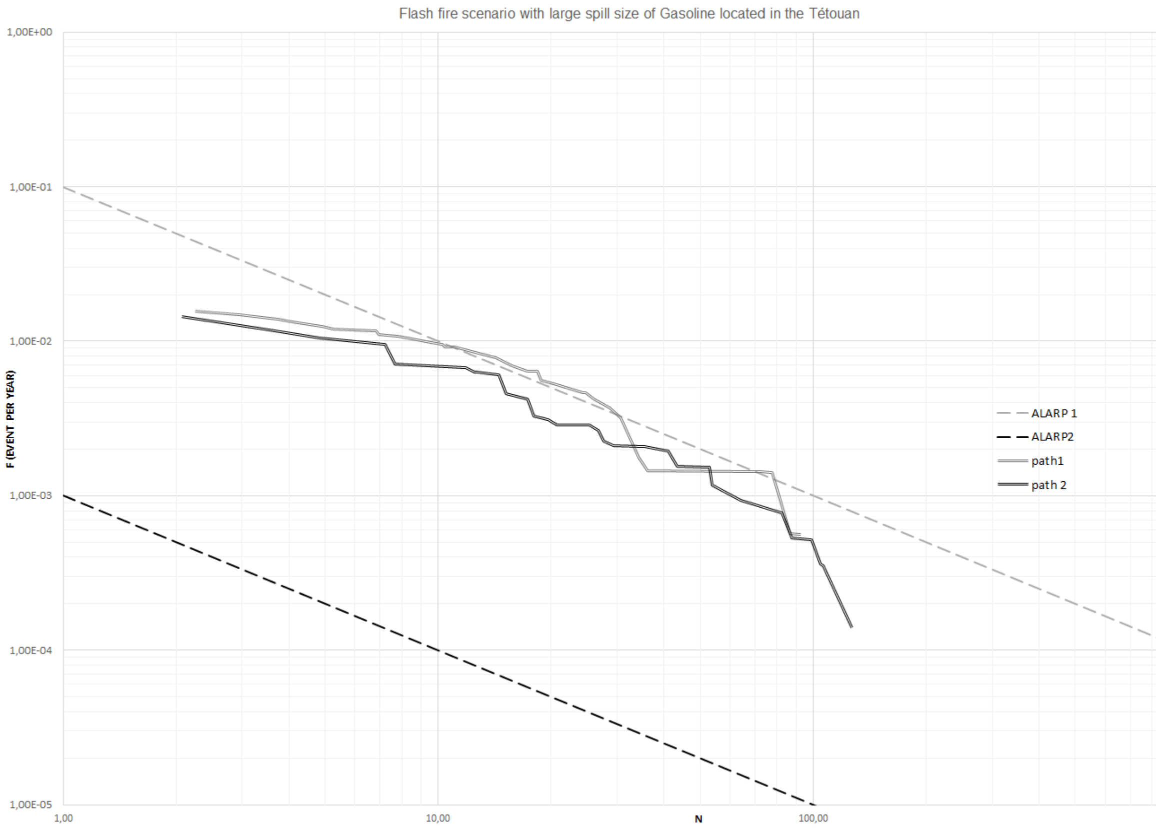
UVCE scenario with large spill size of Butane located in the Tangier.



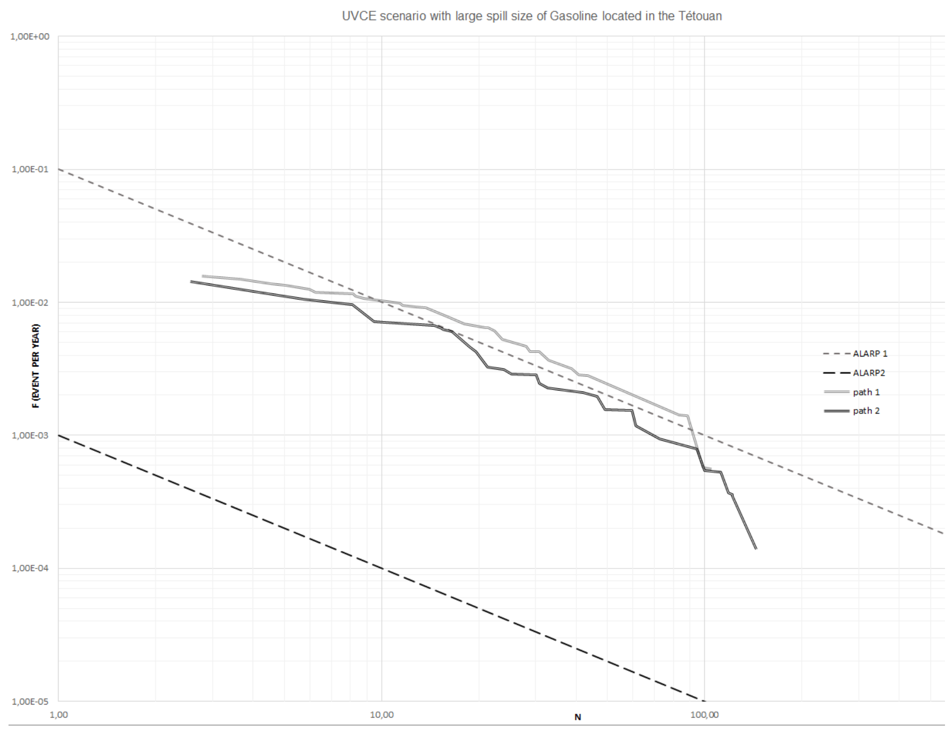
Toxic scenario with large spill size of chlorine located in the Tangier.



Pool fire scenario with large spill size of Gasoline located in the Tétouan.

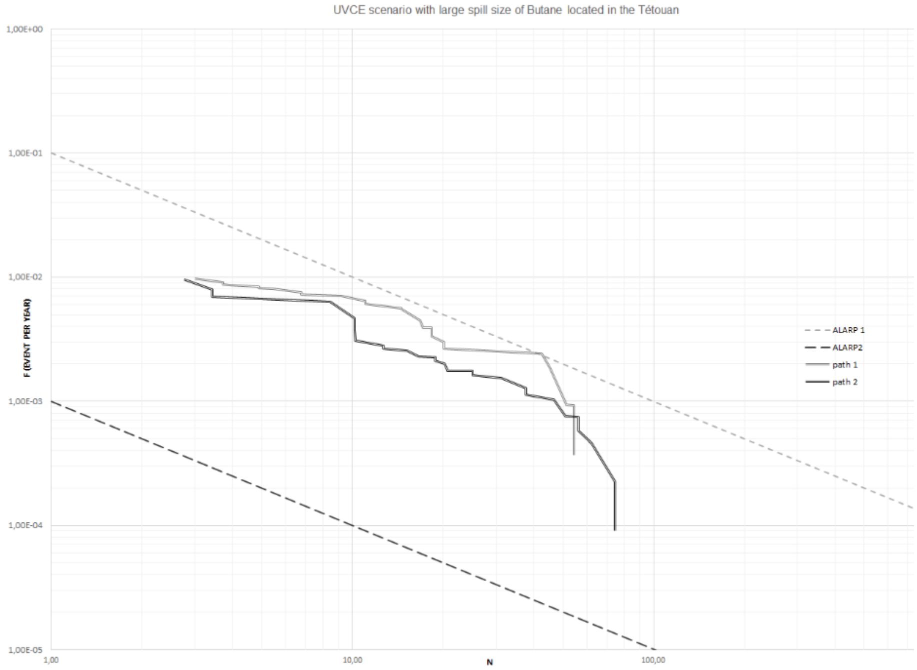


Flash fire scenario with large spill size of Gasoline located in the Tétouan.

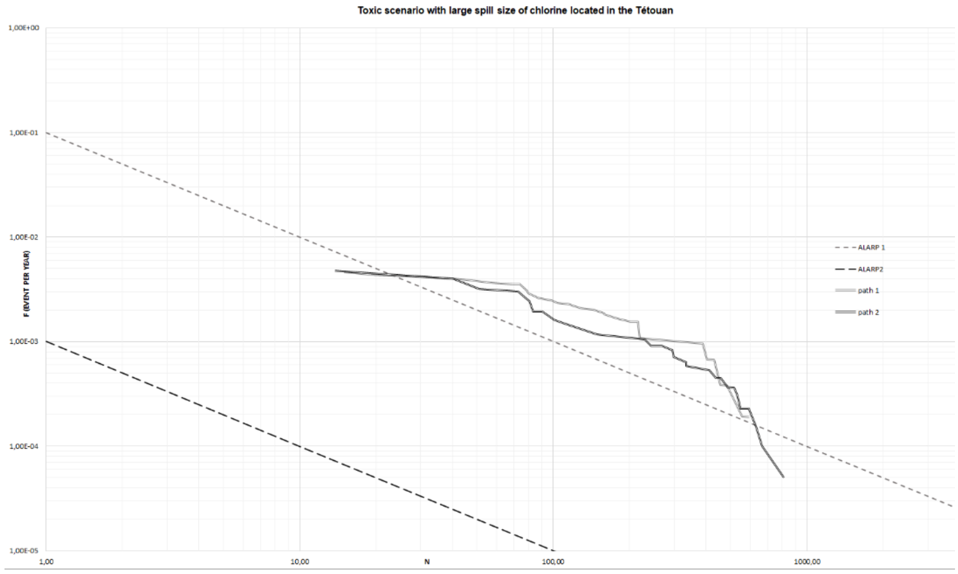


UVCE scenario with large spill size of Gasoline located in the Tétouan.

Flash fire scenario with large spill size of Butane located in the Tétouan



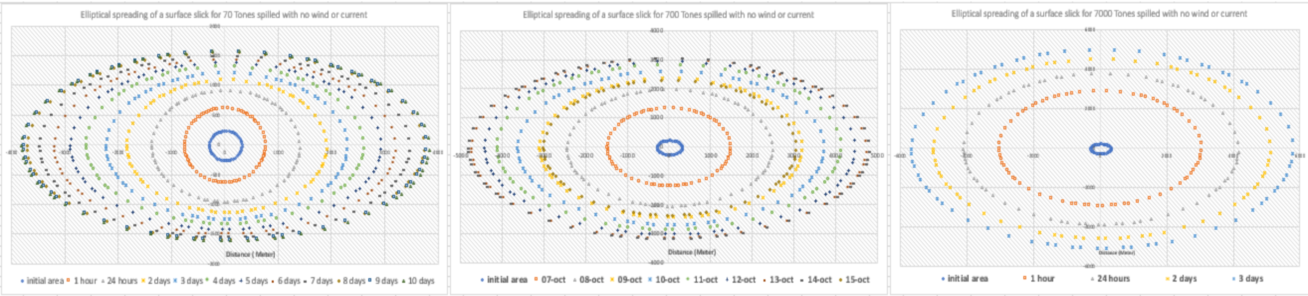
UVCE scenario with large spill size of Butane located in the Tétouan



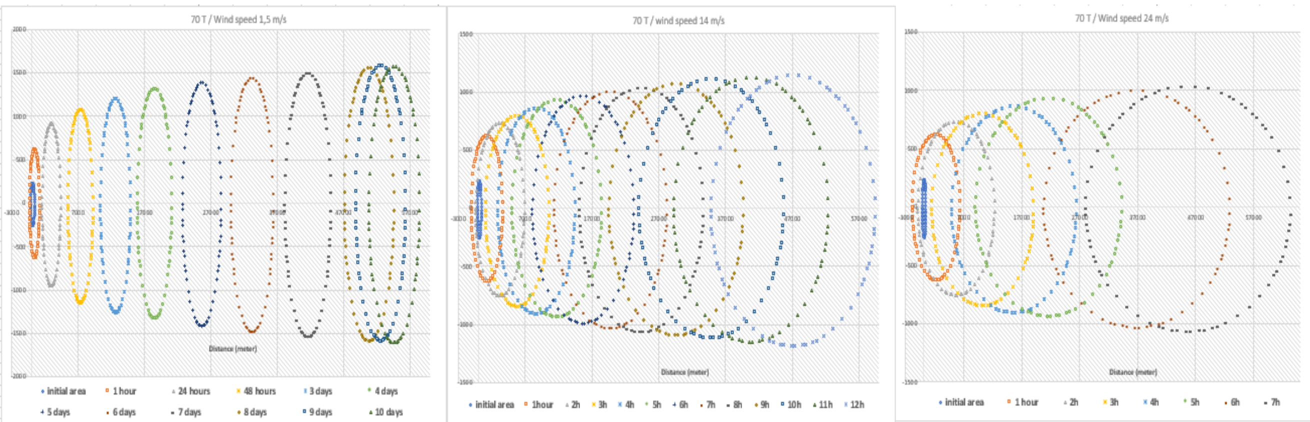
Toxic scenario with large spill size of chlorine located in the Tétouan.

Appendix 2

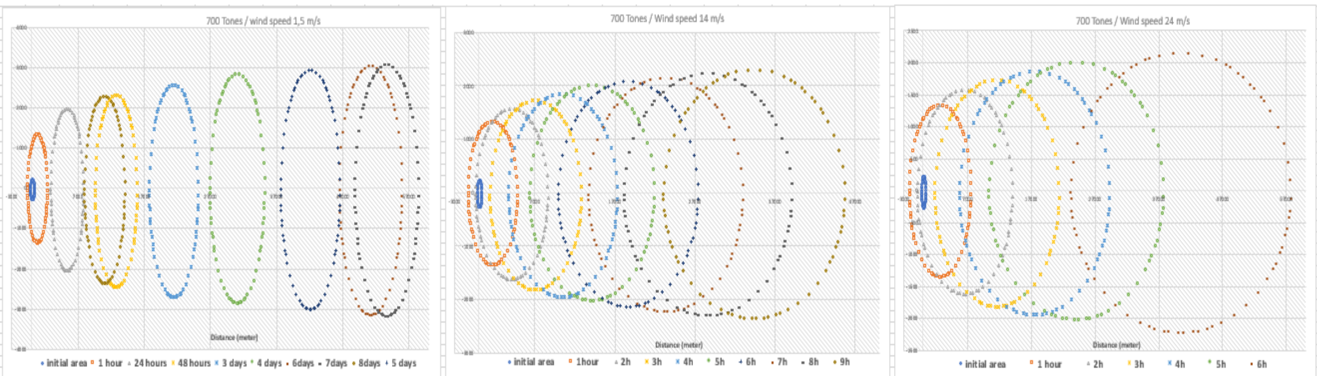
The simulated scenarios which concern a maritime spill accident in the different tests points in Strait of Gibraltar



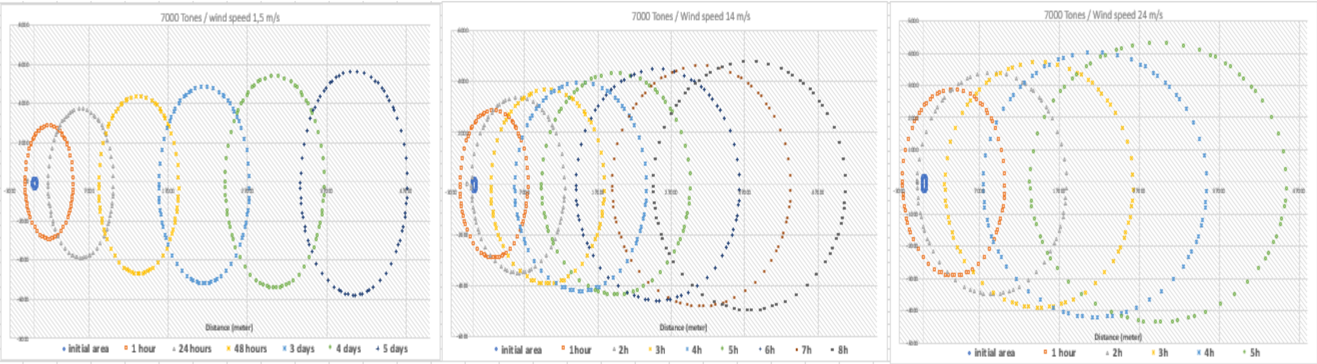
Elliptical spreading of a surface slick for 70 T; 700 T and 7000 Tones spilled with no wind or current.



Estimated Spill location for 70 Tons with wind speed 1.5, 14 and 24 m/s

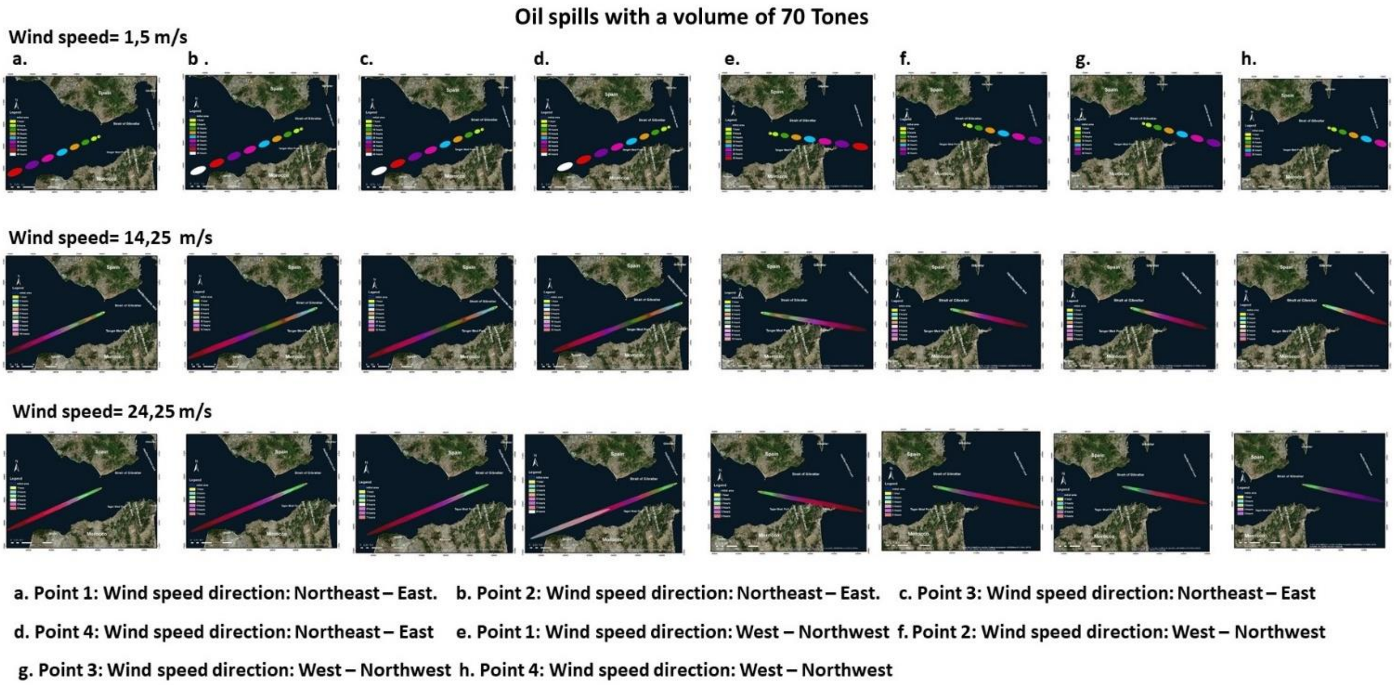


Estimated Spill location for 700 Tons with wind speed 1.5, 14 and 24 m/s



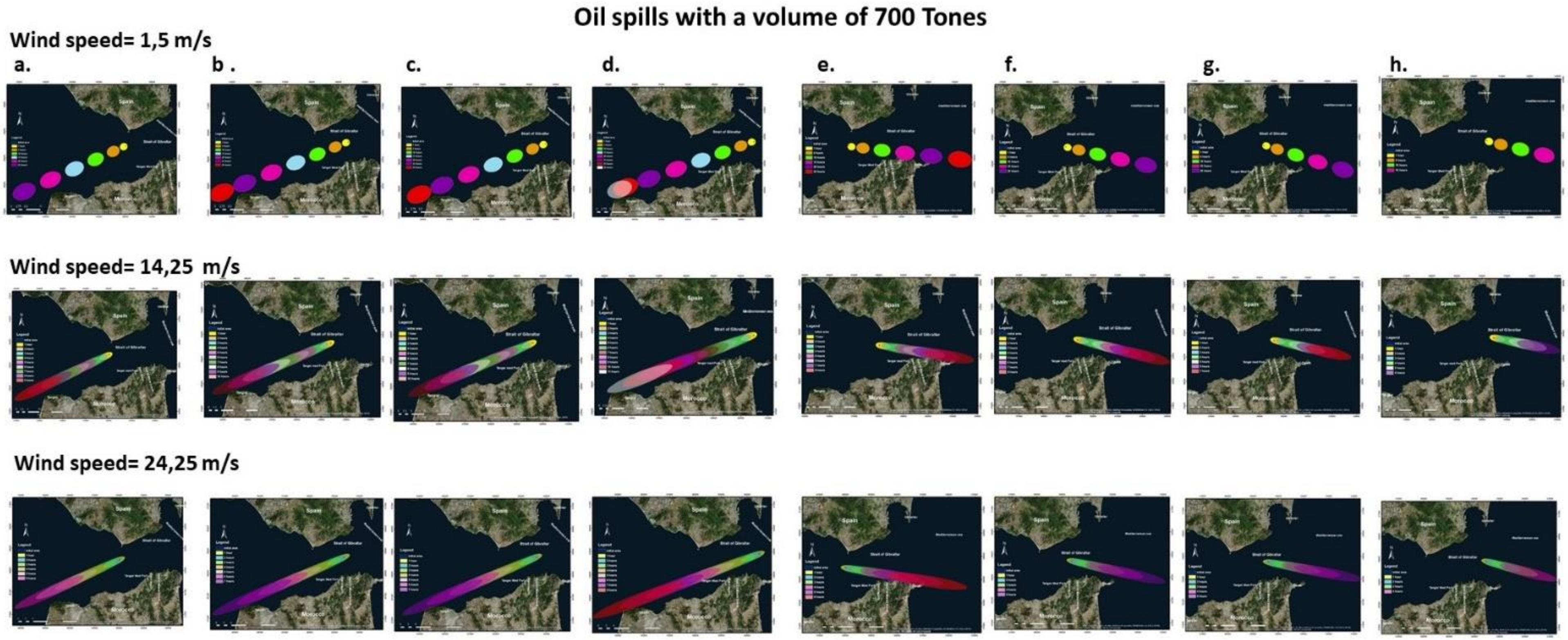
Estimated Spill location for 7000 Tons with wind speed 1.5, 14 and 24 m/s.

Estimated Location of the 70T Spill to Moroccan Coasts



Estimated Location of the 700T Spill to Moroccan Coasts

Estimated Location of the 700T Spill to Moroccan Coasts

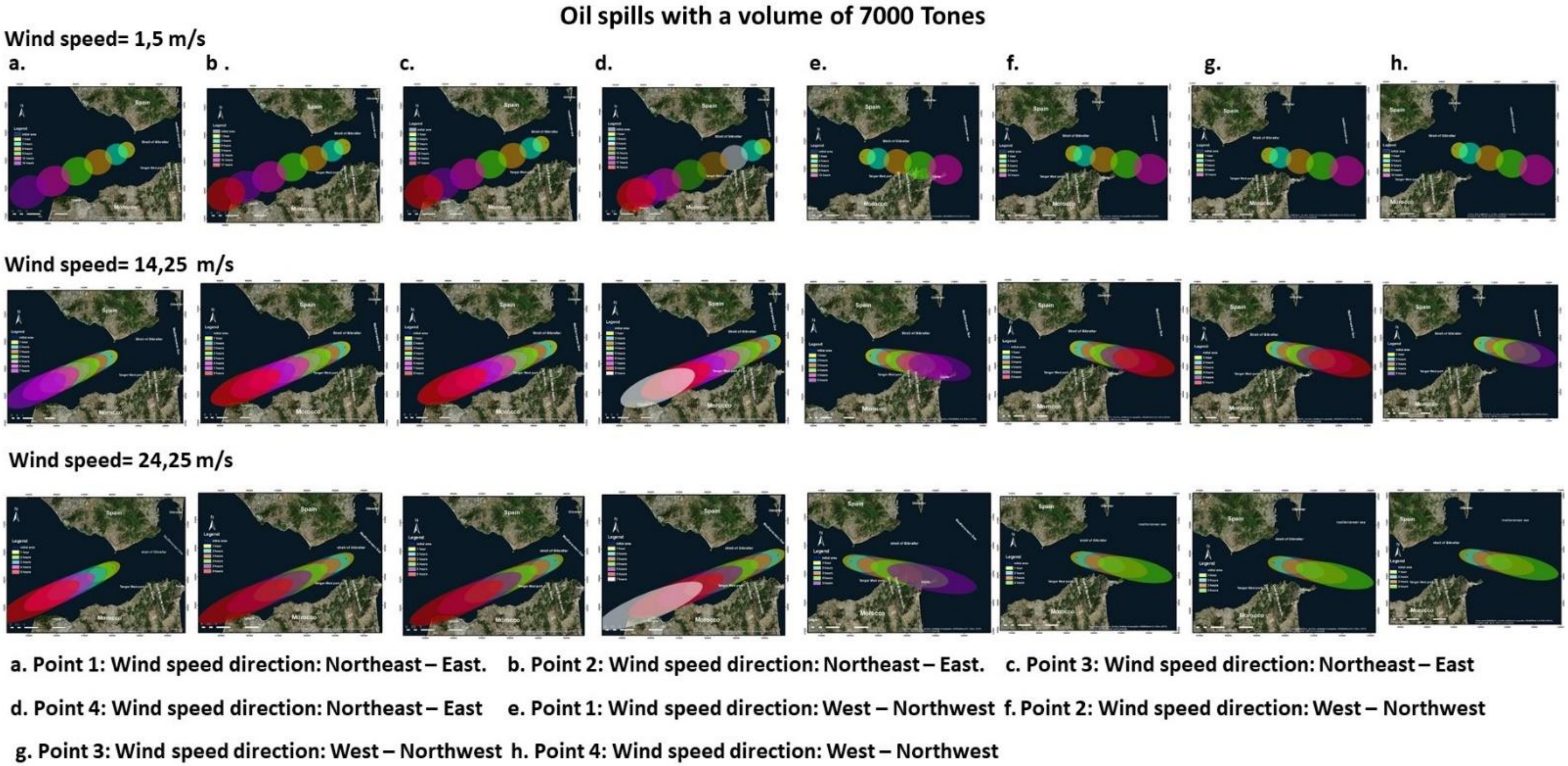


a. Point 1: Wind speed direction: Northeast – East. b. Point 2: Wind speed direction: Northeast – East. c. Point 3: Wind speed direction: Northeast – East

d. Point 4: Wind speed direction: Northeast – East e. Point 1: Wind speed direction: West – Northwest f. Point 2: Wind speed direction: West – Northwest

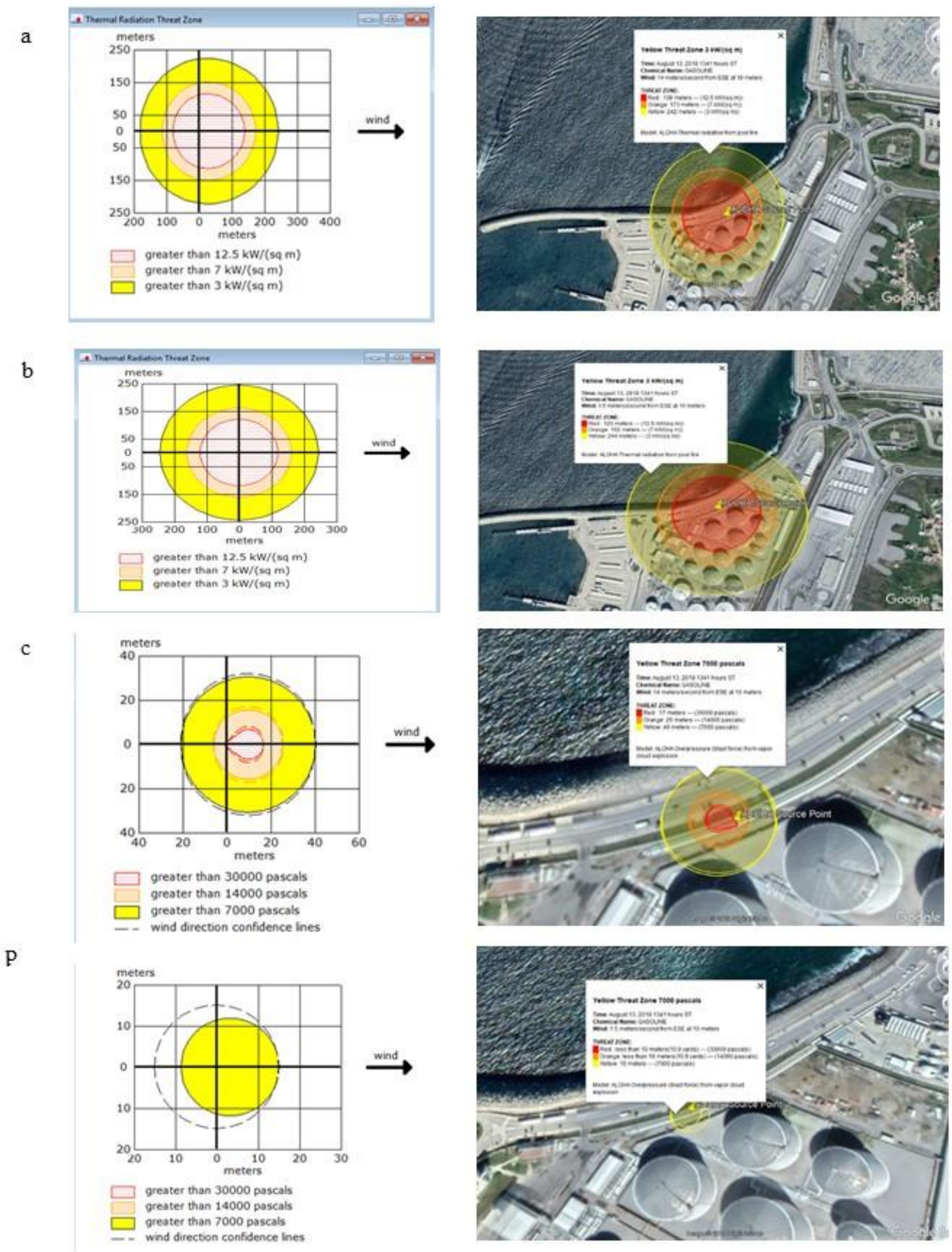
g. Point 3: Wind speed direction: West – Northwest h. Point 4: Wind speed direction: West – Northwest

Estimated Location of the 7000T Spill to Moroccan Coasts



Appendix 3

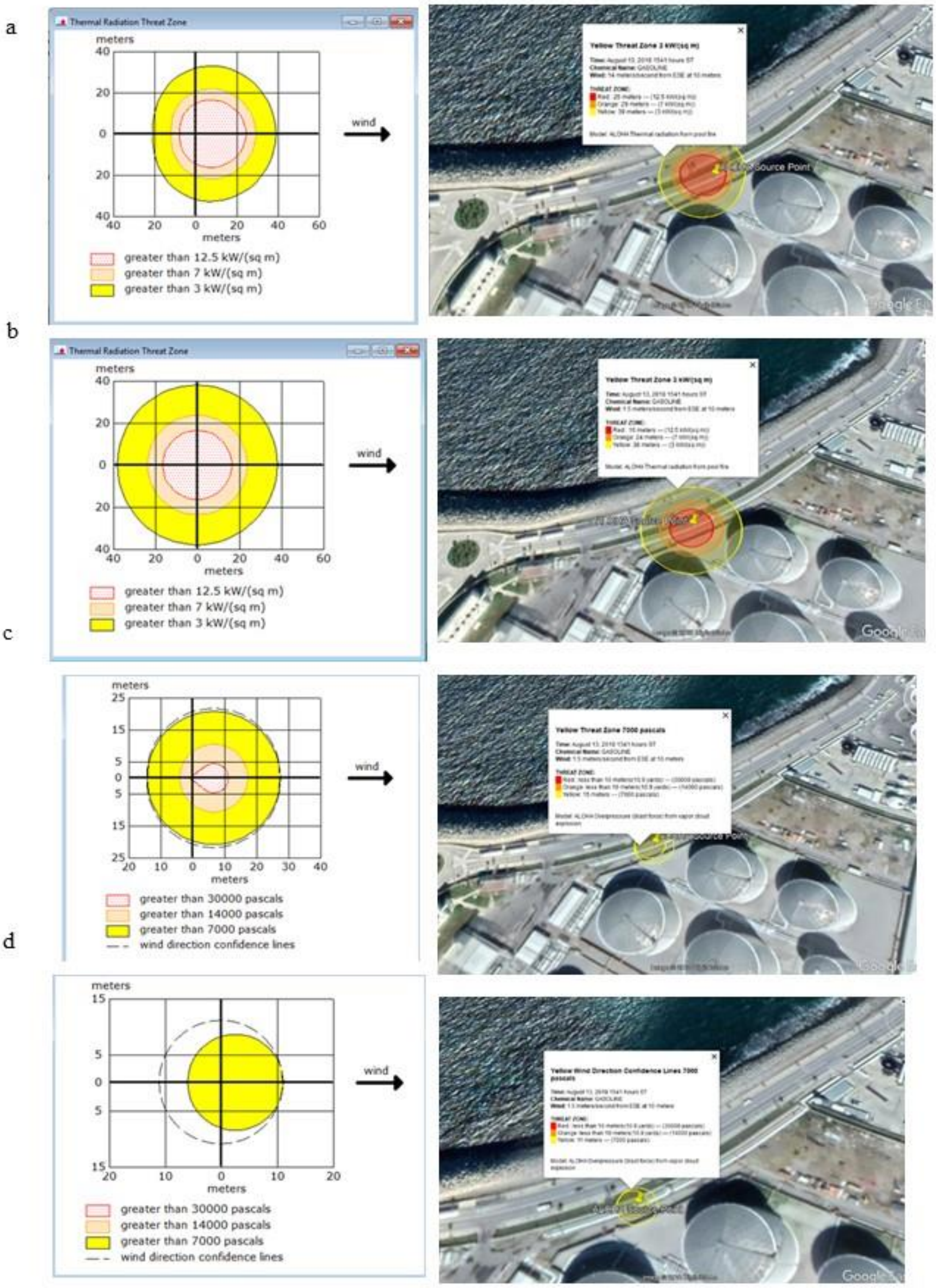
Different incident scenarios computed by Aloha



Event: Partial Break of the Pipe/meters (16")

a: Pool fire thermal radiation threat zone distance from the release source (stability D)
b: Pool fire thermal radiation threat zone distance from the release source (stability F)
c: UVCE Threat zone distance from the release source (stability D)
d: UVCE Threat zone distance from the release source (stability F)

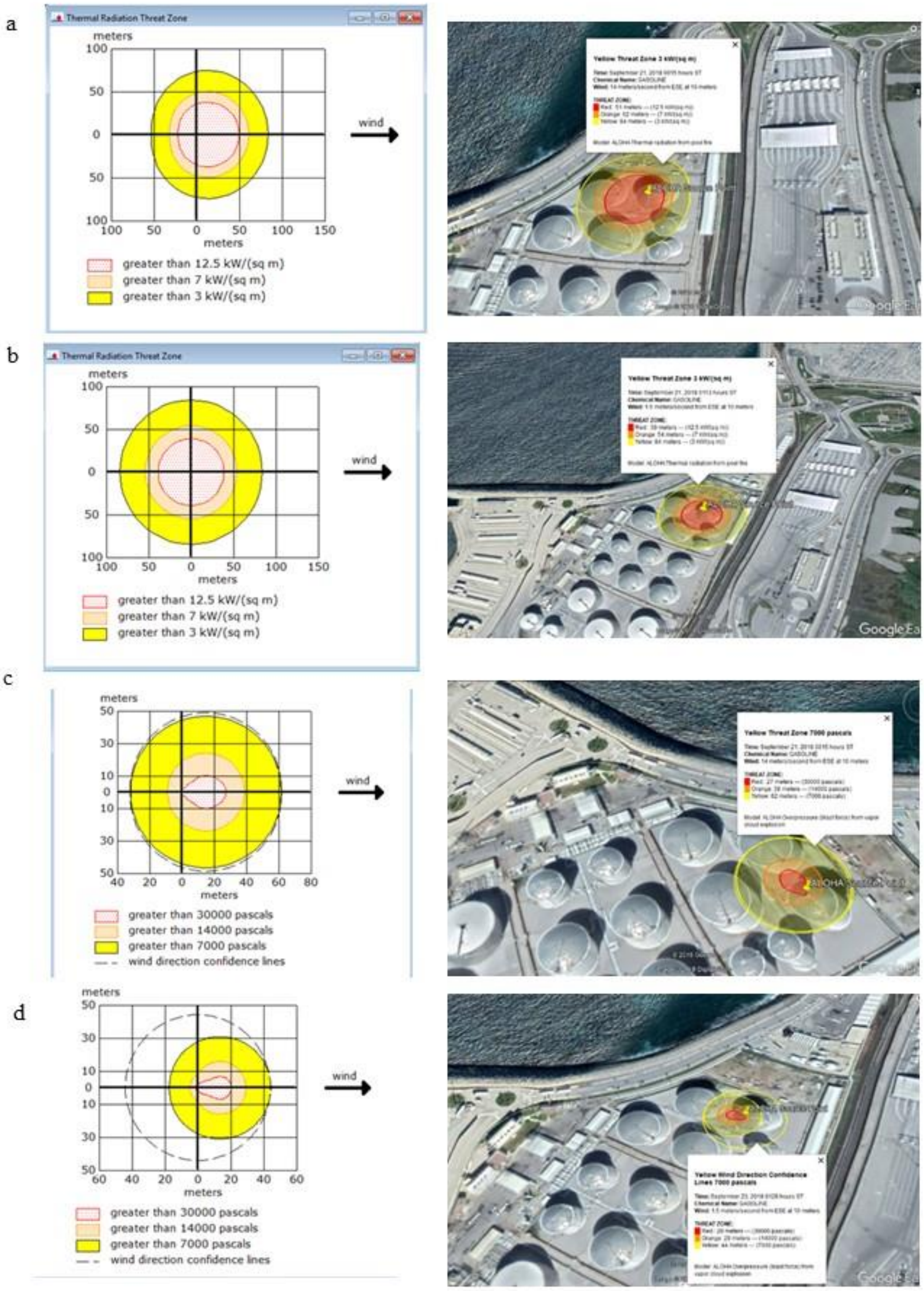
hazard zones for the different scenarios for the partial destruction of the transfer products pipes computed by Aloha



<u>Event: Breaking of the gasket of coupling flange (16")</u>

a: Pool fire thermal radiation threat zone distance from the release source (stability D)
b: Pool fire thermal radiation threat zone distance from the release source (stability F)
c: UVCE Threat zone distance from the release source (stability D)
d: UVCE Threat zone distance from the release source (stability F)

hazard zones for the different scenarios for the overall destruction of the leak from a gasket of the coupling flange computed by Aloha



<u>Event: Partial break of the storage tank</u>

a: Pool fire thermal radiation threat zone distance from the release source (stability D)
b: Pool fire thermal radiation threat zone distance from the release source (stability F)
c: UVCE Threat zone distance from the release source (stability D)
d: UVCE Threat zone distance from the release source (stability F)

hazard zones for the different scenarios for partial the partial destruction of the storage tank computed by Aloha