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## SAFETY OF BUILDING CRITICAL INFRASTRUCTURES AND TERRITORIES

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### ANALYZING DOMINO EFFECTS OCCURRING ON GASOLINE STORAGE TANKS AT THE BULK OIL STORAGE AND TRANSPORTATION (BOST) DEPOT

**Abstract.** Since processed crude oil products are very vulnerable (susceptible) and highly flammable to cause massive catastrophes, such as fire and explosion, which are frequent and can create a chain reaction (Domino effects). This research was carried out at the Bulk Oil Storage and Transportation LTD depot on the Accra plain in Ghana where gasoline and Gasoil are stored. The research was conducted on a flammable gasoline area subjected to a vapor cloud explosion and the hazardous zone. Analyzing domino effects, propagation of a gasoline flammable vapor cloud caused by the explosion, ALOHA (Areal Location of Hazardous Atmospheres) software was used to find out how to apply effective safety measures to prevent future risks at any BOST facilities across the country. After the analysis, it was realized that 5.0 miles to the west-south-west the fuel concentration in the air was 2100 ppm lower than the explosive limit (LEL), and could not be as severe as that at 2.3 miles distance from the source point (12600 ppm LEL) with a greater fuel concentration in the atmosphere. The results made available would be useful in maximizing (improving) safety at the facility, residential area, and as well as minimizing future incidents.

**Keywords:** domino effect, risk analysis, flammable, explosion, hazard, lower explosive limit (LEL)

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### АНАЛИЗ ЭФФЕКТОВ ДОМИНО, ВОЗНИКАЮЩИХ В РЕЗЕРВУАРАХ ДЛЯ ХРАНЕНИЯ БЕНЗИНА НА СКЛАДЕ ХРАНЕНИЯ И ТРАНСПОРТИРОВКИ НЕФТЕПРОДУКТОВ

**Аннотация.** Переработанные сырые нефтепродукты очень уязвимы (восприимчивы) и легко воспламеняются, что может вызвать массовые катастрофы, такие как пожары и взрывы, они случаются часто и могут вызвать цепную реакцию (эффект домино). Это исследование было проведено на складе компании Bulk Oil Storage and Transportation LTD на равнине Аккра в Гане, где хранятся бензин и дизельное топливо. Исследование проводилось на подвергшемся взрыву парового облака участке с легковоспламеняющимся бензином и на опасной зоне. Для анализа эффекта домино от распространения вызванного взрывом облака горючих паров бензина было использовано программное обеспечение ALOHA (Areal Location of Hazardous Atmospheres), чтобы выяснить, как применять эффективные меры безопасности для предотвращения будущих рисков на любых объектах BOST по всей стране. После анализа было установлено, что в 5,0 мили к западу-юго-западу концентрация топлива в воздухе была на 2100 ppm ниже предела взрываемости (LEL) и не могла быть такой сильной, как на расстоянии 2,3 мили от исходной точки (12600 ppm LEL) с большей концентраци-

ей топлива в атмосфере. Полученные результаты будут полезны для максимизации (повышения) безопасности на объекте, в жилом районе, а также для минимизации будущих инцидентов.

**Ключевые слова:** эффект домино, анализ риска, легковоспламеняющийся, взрыв, опасность, нижний предел взрывоопасности (НПВ)

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## 1. Introduction

The consumption of energy has been increasing over the years as a result of both economic and infrastructural development around the world [1]. The chemical industry affords a variety of advanced materials used in our daily life. However, these chemicals have explosive, corrosive and even toxic properties both in their raw and finished forms [2]. Large storage of such chemicals in highly populated areas pose risks, hence the need for a risk assessment to help prevent or mitigate any misfortune is urgent [3]. The research made indicates that major accidents on storage farms are usually as a result of leakages from either process equipment, pipelines or auxiliary facilities [4]. Over the last decade experienced lots of explosions that resulted in several casualties and damage to properties [5]. This is not limited to Ghana alone, but it is a general problem worldwide. For example, there was a fire and explosion at the refinery of BP Products in North America, in Texas City in 2005, which claimed 15 lives and caused more than 170 injuries [6]. Further we listed some other instances around the globe (Table 1).

There are several methodologies that can be used to simulate the spread of various fires, such as a crown (canopy) fire as in [7] or surface fire as in [8] as well as the transition between surface and crown fires in [9]. Likewise, there exist several software tools such as the FARSITE, FlamMap5 and FSPRO that can be applied to predict the probability of occurrence and spread, based on historical records, weather conditions and the topology of the landscape [10]. There has been a lot of researches on accident modelling involving a single unit. There are, however, limited researches relating to domino effect accident modelling, due to their low frequency and complexity [11]. A domino effect occurs when one incident triggers a series of incidents. Reniers [12], Abdolhamidzadeh et al. [13] and Kamil et al. [14], provided several definitions to that effect and they all concluded that an initial event (accident) was responsible for initiating the domino effect. They also agreed that escalation vectors (heat flux and overpressure) were the cause of the propagation of an initial accident to a higher order, depending on the intensity of the escalation vectors.

Table 1

**Major storage facilities accidents**

Date and place	Type of accident (problem)	Description of the accident and its causes	Emergency scale, the max damage zone	Number of victims, damage	Reference
August 6, 2012, Chevron	Leakage and fire	Unit Fire; an atmospheric distillation column with hot diesel like material leaked and caught fire	Fire, toxic gas at the refinery	More than 15,000 people sought medical attention	[27]
June 9, 2015, South Kyiv, Vasytkiv	Leakage and fire	One unit tank leaked and fire spread to the other two	Massive blaze at a fuel storage facility	Three people were killed, and many were injured. One worker was fatally burned in the initial fire	[28]
June 2018, Kemaman refinery, Malaysia	Fire explosion	Fire ignition near a maintenance tank; engulfed in three other giant tanks containing crude oil	Fire explosion, thick black smoke	Six workers perished, facilities were destroyed	[29]
March 18, 2019, Houston, Texas	Fire explosion	One unit tank containing gasoline caught fire and seven others with gas, oil, and chemicals got involved in fire	Thick black smoke and blaze	Schools and residents had to be relocated	[30]
June 2019, Philadelphia	Fire explosion	Fire ignition near a maintenance tank, spread into three other giant tanks containing crude oil	Fire, explosion, thick black smoke	Residents were evacuated	[31]

This study uses the ALOHA (Areal Locations of Hazardous Atmosphere) hazard modeling tool to simulate the potential impact an accident at the Bulk Oil Storage and Transportation Co Ltd. Ghana's (BOST) facility located on the Accra plains in Ghana may have on lives and properties. The ALOHA software is a widely accepted tool used for risk assessment [15, 16]. Renjith and Madhu [17] used it to estimate the individual and societal risk of the ammonia gas. The obtained results in this paper are expected to help the company to evaluate the risks associated with the siting of the oil farm. It can also serve as a reference for policy and decision makers in the field for predicting industrial risks in the country.

### Overview

In December 1993, the Bulk Oil Storage and Transportation Co Ltd (BOST) became a private limited liability company, with the Government of Ghana being a sole shareholder tasked with the distribution of processed petroleum products from its storage facilities located in all parts of Ghana. Furthermore, BOST also holds the Natural Gas Transmission Utility License granted to it by the Ghana Energy Commission (EC) on December 19th, 2012. The NGTU as per (by) EC Act 541, 1997, [18] will provide transmission and interconnection services for natural gas without discrimination throughout the country. Transmission license is:

- to monitor and control the operation of the national interconnected network for the transmission of natural gas in areas within the country and to ensure the safe, reliable and economical transportation of natural gas facilities connected to the transmission system;
- to provide transmission interconnection services without discrimination to other licensees in the natural gas industry;
- to provide transmission interconnection services to operators of natural gas networks in ECOWAS member states.

Having critical responsibilities in the natural gas sector, based on the abovementioned, BOST will plan and develop the transmission system to meet national demand, operate non-discrimination open access transmission system, set up codes and standards for pipeline access, maintain national demand-supply balance, ensure safe, reliable, economic dispatch and operation of NGTU (Natural Gas Transmission Utilities) system. The company will ensure compliance with codes and standards for pipeline access. BOST included building the internal natural gas market to speed up the transfer and distribution. The company has a vast pipeline and storage infrastructure located in the country. These are Accra Plains, Mami-Water, Akosombo, Kumasi Buipe and Bolgataga Depots.

## 1. Materials and Methodology

This section presents the data and methodology used in the analysis. The ALOHA software was used in

the analysis. The site selected for the study is the BOST depot on the Accra plains in Ghana.

This research is based on the ALOHA software program for analyzing the probability spread of fire explosion (domino effect) from the source (gasoline storage tank) on the Accra plains [19, 20]. Now explosion into the same explosive charge (nearby tanks) can have a crucial impact on the yield factor. A probability of the outcome can be explained below:

$$P(A_j) = \prod_{i=1}^N P(B_i), \quad (1)$$

where  $P(A_j)$  is an outcome probability,  $P(B_i)$  is a stage probability leading to the outcome,  $N$  is the number of stages leading to the outcome.

The domino effect principle is applied to this to analyze the probability of fire spread and damages if the source tank explodes in the path and wind direction in Fig. 5. For better understanding a potential scenario at the BOST Ghana gasoline storage tank on the Accra plains is given below, it has (is presented by) four series by Cozzani and coauthors [21].

In accordance with the Primary accident scenario the domino effects are initiated; dispersion is related to the earlier event. The primary scenario and results lead to damages to secondary facilities and systematically go into several facilities, which rapidly results in the increase (boosting) of the domino effect in connection with the first scenario [22].

A similar situation took place at the Accra atomic junction. The accident caused many deaths and destroyed properties. The consequences could explain boosting the domino effects in the scenario described above. Concerning the case study, a similar potential event might occur, so that internal and external domino effect will have considerable effects on several establishments and the residential area as well. The first domino effect accident happened and documented in Texas city. A ship carrying ammonium nitrate exploded, this resulted from a chain of effects, affecting other ships and the crude oil storage near the port causing its explosion, thus killing 600 people and even more [23, 24].

### 1.1. Environmental analysis and data collection

The environmental data of Tema in Accra, including temperature, wind speed, atmospheric stability, relative humidity, and cloud cover was used. The chemical tank location and chemical data were also taken into consideration.

#### ALOHA

ALOHA is an integrated risk analysis model program used in analyzing impacts of accidents, create a threat zone for various types of hazard. These simulations provide information on effective prevention measures and treatment for hazards and casualties; information is designed to be used by safety officers and rescue responders. It has google earth integration for the effective visualization after hazard occurrence [25].



Fig. 1. Stages of fire explosion [26]

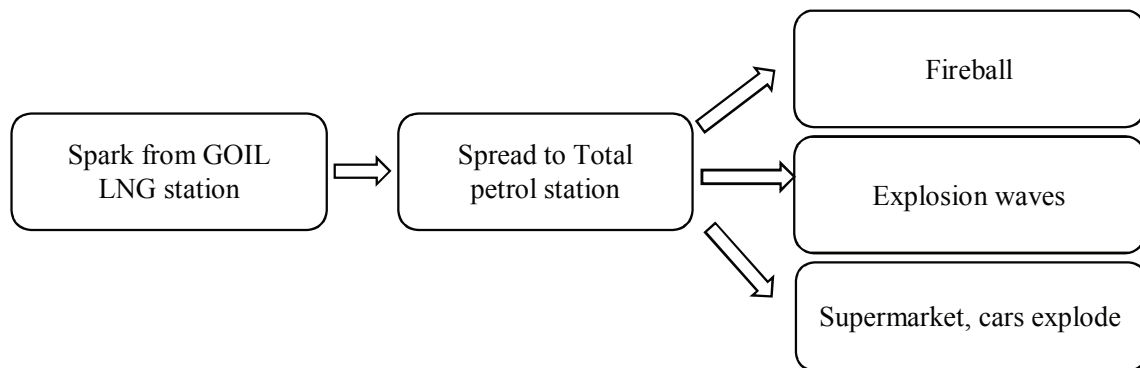


Fig. 2. Domino effects Stages during the Accra Atomic junction accident in Ghana [26]

Wave pressure and radiation can be determined after the flammable substance is released to the atmosphere by the source ignition [26]. Fire explosion in storage complexes and refinery industry account for 85 % of accidents and damage. The rest are related to spillage and toxic gas release, respectively. Property damage is difficult to account. Table 1 shows related accidents from different locations.

### 1.2. Case study

The industry this research is related to is the bulk oil storage and transportation Co Ltd (BOST) in Ghana, one of their storage facilities is located in Accra plains and is the largest of all the facilities they have. It has a total capacity of 210,500 cubic meters, Gasoline of 125,000 cubic meters, Gasoil of 90,000 cubic meters and the terminal has 15 tanks in all, 12 of which are operational. The facility is too close to the residential area, with the run on the google map elevation of 34 m, 4.25 km east and 1.48 km north. In this existing facility, the stakes are extremely high; therefore, safety must be paramount importance in daily operations. It is essential to use appropriate methods to identify a potential or probable incident that might occur [32]. In this situation, severity and likelihood of any hazard occurrence are implied, identifying risk activities [17]. Hazard identification deals with collecting and identifying risks and most technical monitoring that can specify any danger in the workplace or surrounding; these duties are performed by a qualified safety

consultant or safety engineer in the industry premises, thereby investigating the higher potential risk and hazard quantifying (quantitative risk assessment) is termed Risk Assessment [33, 34]. Hazard operability and domino effects can be one of the best tools to identify risk. This research is focused on such risks like fire explosion, hazardous substances, toxicity effects as well as consequences of the discharge of this substance at industrial facilities which would be determined for potential danger further in the paper.

#### The potential scenario for BOST facility modeling on the Accra plains

Gasoline and Gasoil storage tanks, at the Accra plains depot include of 15 tanks, 12 of which are operational. Before this project, data was collected. The data provides the following: the tank properties, such as size, type of the chemical in the tank, thickness, etc., it makes reference to the library and Internet resources, and operation of reservoirs. Climate data was obtained from Internet weather reference site and was used, taking the average of humidity, temperature and wind speed for six months of the year. The Landscape and potential explosion hazards associated with this scenario were studied. All the factors above were analyzed using ALOHA software, the results of the analysis are given. We prepared actions against the potential threat and the domino effect that might happen in the study area. However, the consequences of the steps taken are also provided.



ALOHA software’s methodology is to create an event scenario and collect data for this scenario, using a real example of the location of this event, which can be represented in the following steps:

- scenario;
- data entry of the area for modeling;
- atmospheric data;
- chemical data.

Scenario — in this situation, the gasoline is stored in the reservoir and the latter is considered from the perspective of the potential explosion and its related risks and hazards (Fig. 3).



Fig. 3. BOST tank farm depot location.

Red (1) — ALOHA source Point, Blue (2) — residential area,  
Green (3) — gas oil tanks

In addition, the situation is modeled in the following conditions.

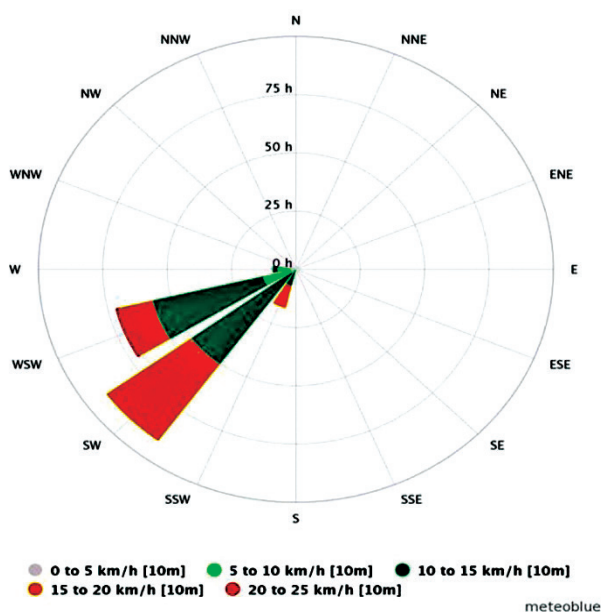


Fig. 4. Wind rose Tema, Ghana [35]

Table 2 explains and provides the atmospheric parameters, that were used in this study.

Table 2

**Meteorological Data**

Description	Amount/parameter	Unit
Wind Speed	12	Miles per hour
Wind Direction	Two at WSW	meters
Ground Roughness	Open country	—
Air Temperature	27	°C
Inversion Height	No	—
Cloud Cover	3	tenths
Stability Class	D	—
Relative Humidity	25	%

Table 3 gives information concerning the location of the tank storage on the Accra plain of the Bulk Oil Storage and Transportation (BOST), which was taken from google earth.

Table 3

**Location Information**

Location	Latitude	Longitude	Altitude
Accra plains depot	5°39’N	0°01’E	12 m

Table 4 gives the properties and data of gasoline (petrol chemical) information for the study.

Table 5 gives the information about tanks and related tanks near the scenario, gasoline tank that was considered in this research.

**2. Results and Discussions**

The possible accident that might happen according to the run data, explosion of the flammable gasoline area of the vapor cloud. From the source atmospheric storage tanks we got the output explosion results that could also affect the nearby tanks that contain gasoil and gasoline. The gasoline flammable area of the vapor cloud explosion given below in Table 6.

Concerning this potential scenario, any part of the flammable area of the vapor cloud explosion that would be above 2100 ppm can result in an explosion. Because gasoline, and oxygen are mixed in the atmosphere. Furthermore, the danger zone or threat zone increase depending on the severity of the explosion wave at each level, this is divided into two stages from the ALOHA source point, as it is shown in Fig. 5.

The gravity of the wave caused by the explosion of the flammable gasoline area of vapor cloud explosion is shown in the red zone (1), which covers a distance of 2.3 miles from the direction of the wind in the BOST depot to the west-south-west at Accra plains and which is more significant at 12600 ppm (60 % LEL = flame pockets).

The yellow marked area (2) is the one where the intensity flammable area of the vapor cloud explosion reduced to (by) 10 %, but is 2100 ppm at 5.0 miles distance

Table 4

**Chemical Data**

Chemical name	Molecular weight	ERPG-1	ERPG-2	ERPG-3	IDLH-1	LEL	Boiling point	Freezing Point
Gasoline	72.00 g/mole	200 ppm	1000 ppm	4000 ppm	1100 ppm	21000 ppm	395 °F	-40 °C

Table 5

**Storage Tank Data**

Liquid level in the tank	Storage tank capacity	Chemical and status saved (stored)	Storage gas temperature	Tank diameter	Tank height	Tank model	Season	Number of tanks
70 %	24,937,962	Gasoline — Liquid	25 °C	42 m	18 m	Cylinder	Warm	4
64 %	24,937,962	Gasoil — Liquid	27 °C	42 m	18 m	Cylinder	Warm	3

Table 6

**Results of the potential scenario for the flammable gasoline area of vapor cloud explosion**

Parameter	Threat zone distance	LEL	Flame surface
Yellow	5.0 miles	2100 ppm = 10 %	Limiting Oxidant Concentration
Red	2.3 miles	12600 ppm = 60 %	Flame pockets

from the ALOHA source point downwind of the depot to the east-north-east of the Accra plains.

In the scenario, according to Fig. 5, any red area coverage is a flammable area of the vapor cloud explosion greater than 60 % LEL, that would explode and get fire with a series of damages. Hence, modeling a flammable gasoline area of a vapor cloud explosion shows the threshold concentration of fuel in the air, when a flammability hazard may exist, which is shown by the red and yellow areas on the map and the graph. It is also shown that the red and yellow are the gasoline concentration vapor in the atmosphere, hence any contact with ignition or a spark would result in fire explosion because it has the mixture of air and fuel to start burning. For quantitative risk assessment of fuel vapor mix with air flammable greater than 12600 ppm, structures and heavy losses would be incurred (domino effect) in series. The results obtained from ALOHA indicate the nearby reservoir in 669 meters to the west would also be affected, resulting in a massive explosion if the source tank explodes, which will moun (cause) a considerable damage (from the coverage area in Fig. 5, b. Risk analysis within risk assessment is straightforward in contrast with a quantitative risk assessment which takes the starting screen of a Domino effect propagation, then QRA, which needs imputing limited data [36].

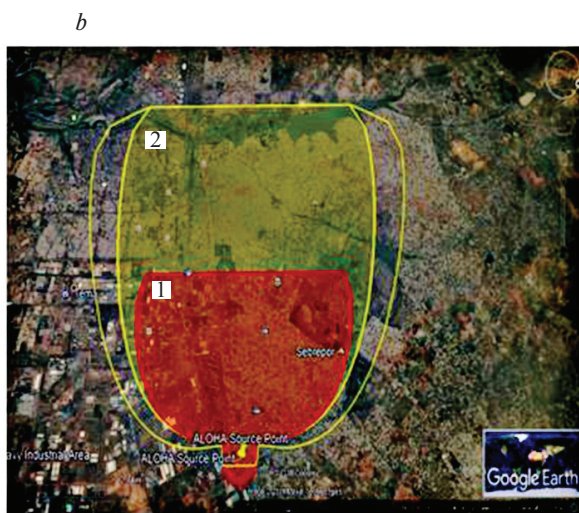
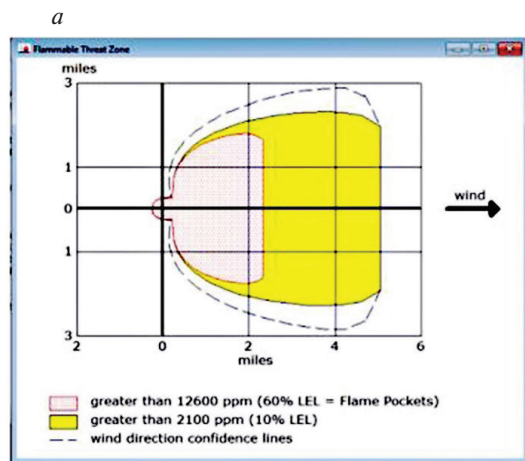


Fig. 5. Flammable threat zone: a — graph, b — google map

**Safety guidelines and prevention**

Keeping this in mind, gasoline storage in Accra is limited in order to meet the growing market at the southern border of Ghana. Many of such facilities are built close to residential areas, therefore the risk of toxicity, explosion, and fire hazard severity is going to double. Information regarding the safety of oil refinery companies, storage and transporting companies are strictly not adhered to. Recommendations to reduce future accident related to fire, explosion, toxicity risks are given below:

- risk information exchange program;

- use of safety signs in a high-risk location;
- use of fire alarm and amplified alarm;
- application of heat sensors and smoke detectors, fire detectors around the tank area and loading bay;
- adopting the passive defense, this is very effective against all kinds of risk (it consists of good urban plan and an architecture design of the facility, which can reduce any natural and human-made threat concerning this type of scenarios [37]);
- construction projects must consider quick evacuation and avoid being located close to a residential area;
- in the process of designing reservoirs safe reservoir radius must be taken into consideration [38, 39];
- regular inspection and identification of potential faults of ignition are of paramount importance;
- emergency radio phone should be available to workers and security officials;
- the authors [40] suggested a software tool called to determine the domino impacts (in the order of priority) at an industrial plant, on one or several levels on the site.

### Conclusion and Recommendations

In this research, Domino effects are shown to be very challenging, this applies to models and estimates of probability, data spread, and complexities of the analysis carried out and is still substantial [39]. People are well aware of the risks but do not systematically mitigate them. According to the scenario and the concerning the BOST facility (ALPHA source point), the accident caused the human fatality and damage (the flammable area of the vapor cloud explosion) within a high range of 2.3 miles of 12600 ppm in a flame pocket.

Furthermore, downwind property loss is estimated greater than 12600 ppm in modeling Fig. 5, This study gives precise results for ensuring safety for the personnel on the self-assessment, and carrying out a safe zone which would be a border of 4.0 miles, separating residents from the industrial facility. Domino effect occurrence can be mitigated or curtailed; flammable tanks should widely be separated from each other.

Moreover, tank vehicles for filling should be kept at an appropriate safety distance to reduce the possible damages and fatality. The study also provides a comparison between previous events and future event that might occur accompanied by a domino effect and consequences relating to the BOST facility, including the Accra plain, Kumasi and the northern part of Ghana [41, 42]. For us to reach the practical result, two or more modeling program should be considered and run for better comparison and concrete outcomes: such software program as FLACS [43], SAFETI — DNV GL [44], and TOXI+Risk [45].

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