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A systematic approach for risk assessment in LPG storage tanks area – SKIKDA refinery.

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ABSTRACT/RESUME

Abstract: *In this work we present a risk assessment methodology, Implemented based on the integration of two methods D-HIGRAPH and HAZOP. The approach is applied on the LPG storage Area in SKIKDA refinery (the most important refinery in Algeria). Several recommendations raised from the study to improve the plant safety. The study is completed by simulating the effects resulted from an explosion in the sphere S-151 (for butane storage) using ALOHA Software. In simulation, the following cases are considered: the explosion effect, the toxic material release and the thermal effect of flammable material release, the results are mapped on the refinery map to indicate the exact threated zones.*

I. Introduction

During the last few years, several techniques and standards concerning hazards identification and safety analysis have been published [1 -6] . The most known tools in the field of chemical engineering are: safety reviews, process hazard check list, Bowtie analysis, hazard and operability study (HAZOP), failure modes and effect Analysis (FMEA), fault tree analysis (FTA), Event tree Analysis (ETA), safety integrity level (SIL), and Layer of protection analysis (LOPA) [7-14].

A clear process description is the key idea behind performing any effective hazard analysis. It helps in defining the different interactions between the system components, and the causes/or consequences for any studied phenomenon. Functional graphs are powerful tools introduced recently in risk assessment field. The aim is to give a clear and simple graphical presentation for the considered model, this helps in defining the dangerous scenarios and the different causes of any accident. Another important advantage is that, the functional graphs consider the system in global view i.e. to capture the functional as well as the structural aspects of process plants [15-17]. This feature will help to solve the problem of complexity that characterizes the chemical plants, and lets the risk assessment operation easier and clearer, the fact that helps in detecting the different dangerous scenarios.

The aim of our work is to improve the safety of an LPG storage area. Through the implementation of a functional model using D-HIGRAPH, followed by the examination of all expected scenarios using HAZOP and at the end, we use the software ALOHA to simulate the effects of the dangerous scenarios on the neighboring sites enviorement.

Several recommendations are raised to help in improving the safety of this critical area.

II. Materials and methods

As it is mentioned in the previous section, in our work we will consider the following procedure: first, the system is modeled using functional graphs (D-HIGRAPH) we consider only one sphere (S-151) and the same conclusion will be generated for other spheres and bullets. In the second step, we apply the HAZOP to examine all the expected situations using key words and deviations. The causes and the consequences of each deviation as well as the existing safeguards will help in the deep determination of the dangerous scenarios that may affect the system, in case where the existing safegurds are not sufficient to protrect the system, recommendations should be offered for additional safety measures. At the end, the dangerous scenarios are simulated using ALOHA software to indicate the exact consequences on human health, material loss and environement pollution.

II.1. HAZOP (Hazardous and Operability method)

HAZOP study is the most importand dysfunctional method for risk assessment. It is widely used by the petrochemical and chemical companies, since it consider the product flow through the limit batteries of any production facility. In HAZOP, the plant is divided into nodes and streams, where all strategic equipment and sections are considered as nodes. Each node may be divided into streams where each stream is dedicated to a specific product for example one stream for the process product, and the other for the utilities materials. Executing the method based on the use of guidewords (such as, no, more, less) combined with process parameters (e.g., temperature, flow, pressure). The multidisciplinary HAZOP team examines all expected situation in the aim to identify the expected malfunctions, by highlighting the causes of the deviation along with the consequences and the existing safeguards. In case where the existing safeguards are not able to prevent the accidents recommendations are raised to add other safeguards, the flow chart of Figure 1 summarizes the steps that generally followed in implementing a HAZOP study [18-21].

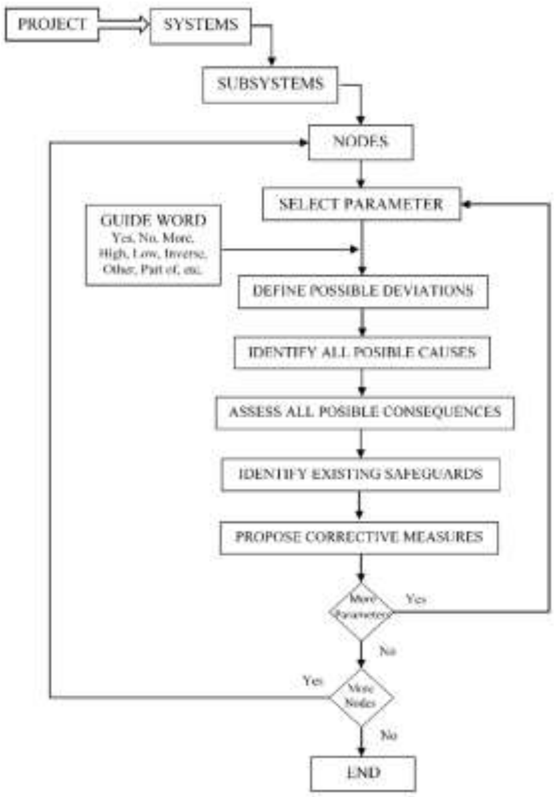

Figure 1. *HAZOP methodology*

II.2. D-HIGRAPH and functional modeling

Functional modeling is an approach used to model any man-made system by identifying the designer overall goals and the functions/tools used to achieve these goals. It is widely used in representing the purposes and functional organization of complex dynamic systems [14] [21-22].

II.2.1. Definition

D-HIGRAPH [14],[22]. is an adaptation of HIGRAPH proposed by Harel (1987, 1988) which in turn an adaptation of famous Venn diagrams (John Venn 1880), A Venn diagram uses overlapping circles or other shapes to illustrate the logical relationships between two or more sets of items as it is indicated in Figure 2

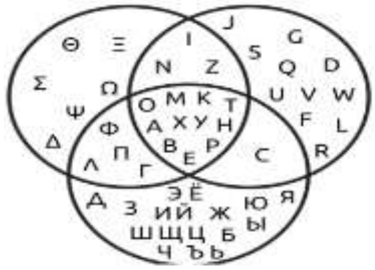

Figure 2. *Venn diagram* [14]

HIGRAPHs consist of two elements, blobs (states) and edges (transitions) in connecting the blobs; we cannot go from one state to other only if the transition (edge) is validated.

D-HIGRAPHs have the same structure as HIGRAPHS. Both consist of blobs and edges, however the differences in their interpretations, such that the blobs represent a function in D-HIGRAPHS rather than state in HIGRAPH, the same thing for edges which are considered as states in D-HIGRAPHS and transition in HIGRAPHS. Figure 3 shows an example for a process description using D-HIGRAPH, which can be interpreted as follows: the actor (structure-related) performs the function if the state is enabled and if the condition inside the blob is true.

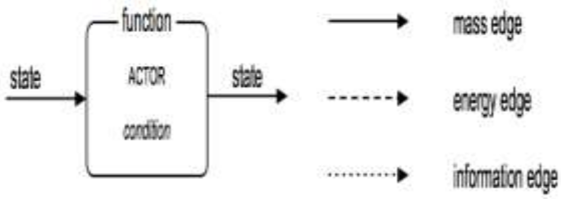

Figure 3. *D-HIGRAPH Basic blob and types of edges* [14]

II.2.2. D-HIGRAPH qualitative simulation

Similar to HAZOP study the D-HIGRAPH approach uses the reasoning based on deviation (not on failure as in FMEA). In D-HIGRAPH, the system description is made in three different layers:

- Structural description: specification of the variables that characterize the system. If we consider a process plant, the most common variables are: flow (F), temperature (T),

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composition (x), pressure (P), energy (E), information (I), level (L), valve opening (O), etc. These symbols will be used across D-higraphs.

- Behavioral description: in this step we present the potential behavior of the system as a network. The relation between the process variables is realized via the qualitaive physics constraints M^+ and M^- [14] the relation is mathematically expressed by the following equation (eq 1)

$$Z^{X_1, X_2, \ldots X_n}_{Y_1, Y_2 \ldots Y_m} \Leftrightarrow M^+(X_i, Z) \wedge M^-(Y_j, Z)\ \forall i, j \quad \textbf{(1)}$$

Which means that variable Z is related to the n variables X_i by a M^+ constraint and with the m variables Y_j by a M^-. Figure 4 indicates the different situations for the system behavior with respect to the constraint variabes M

- Functional description: In this layer, we introduce the Purpose of connection between the different structural components as it is indicated in the D-HIGRAPH layout. [22].

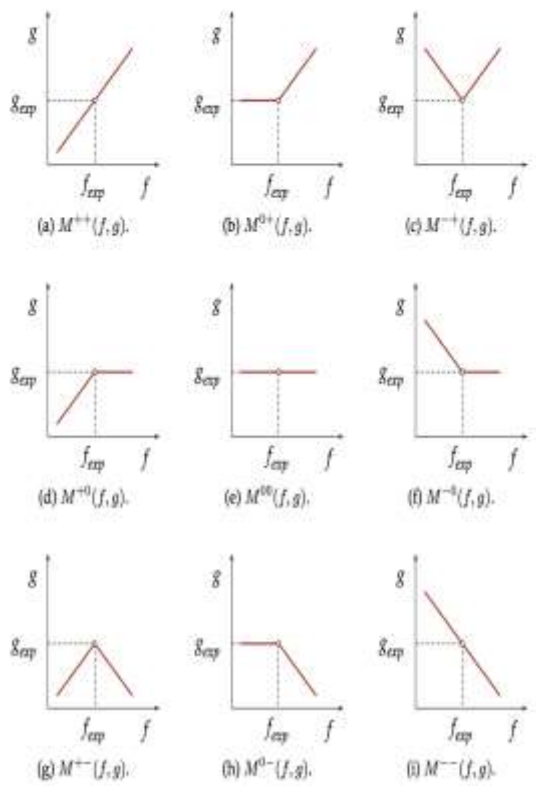

Figure 4.*The constraint family* [14]

II.3. ALOHA Software

ALOHA® is powerful modeling software developped by CAMEO® software suite, it belongs to a series of softwares developed to model the impact of dangerous scenarios generated by chemical emergencies such as (PHAST of DNV [23]) . It allows the engineer to enter details about a chemical release by considering the weather details, the geographical locations, equipment dimesions , the materials nature etc. The software will generate the threat zone estimates for various types of hazards. ALOHA can model toxic gas clouds, flammable gas clouds, BLEVEs (Boiling Liquid Expanding Vapor Explosions) [24-27], jet fires, pool fires, and vapor cloud explosions VCE. The threat zone estimates are shown on a grid in ALOHA, and they can also be plotted on maps in MARPLOT® Esri's Arc Map, Google Earth, and Google Maps. The red threat zone represents the worst hazard level, and the orange and yellow threat zones represent areas of decreasing hazard [29-31].

III. Simulation and results

III.1. Process description

Skikda refinery RA1K is the most important refinery in Algeria it is located in the east of Algeria, around 600 Km far the capital Algiers. The refinery is mainly divided into two production trains. Each one include one CDU (crude distillation unit called U 10 and U11) and gas plant units called U30 and 31. The crude is first separated to three main components in the CDUs, which are light components (gases), Naphta and residues (heavy components). The light components are treated in the gas plants units and again separated to commercial products (propane, butane,..). The products are stored in an LPG storage tanks area (Figure 5) which consists of several spheres and bullets. The area also receives products coming from Skikda refinery 2 (RA2K) another small refinery for distillate treatement [32].

III.2. LPG storage D-HIGRAPH model

The D-HIGRAPH model for sphere S-151 is shown in Figure 6 such that the main patrameters that are controlled in the system are Temperature (T), Level (L) and Pressure (P). the objective is to provide a specific conditions that let the product respects the predefined commercial specifications.
We use a dedidicated loop (composed of a sensor, controller and valve) to control each parameter such that (Loop 1 is used for temperature, Loop 2 for pressure and Loop 3 for level).
A cooling system is used to keep the temperature in a normal condition .ie. We use the flow of cooling water (F1) as tool to control the temperature.
We use the LPG flow (F2) to control the sphere level through the colosing and opening O3 of valve 6304.

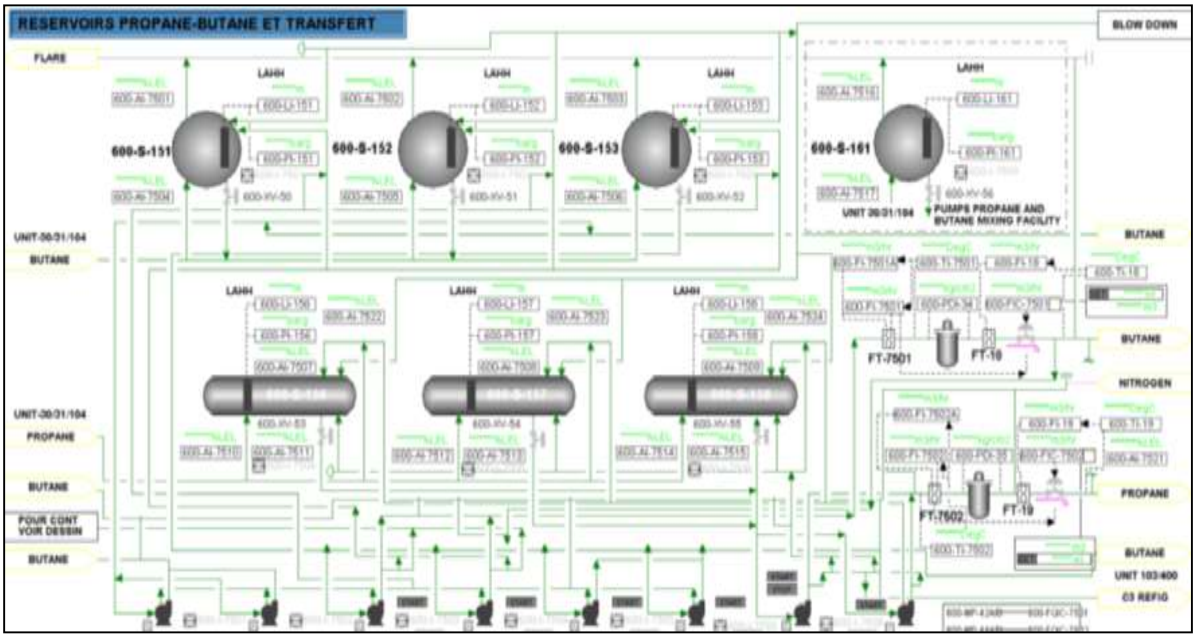

Figure 5. *RA1K LPG storage area* [32]

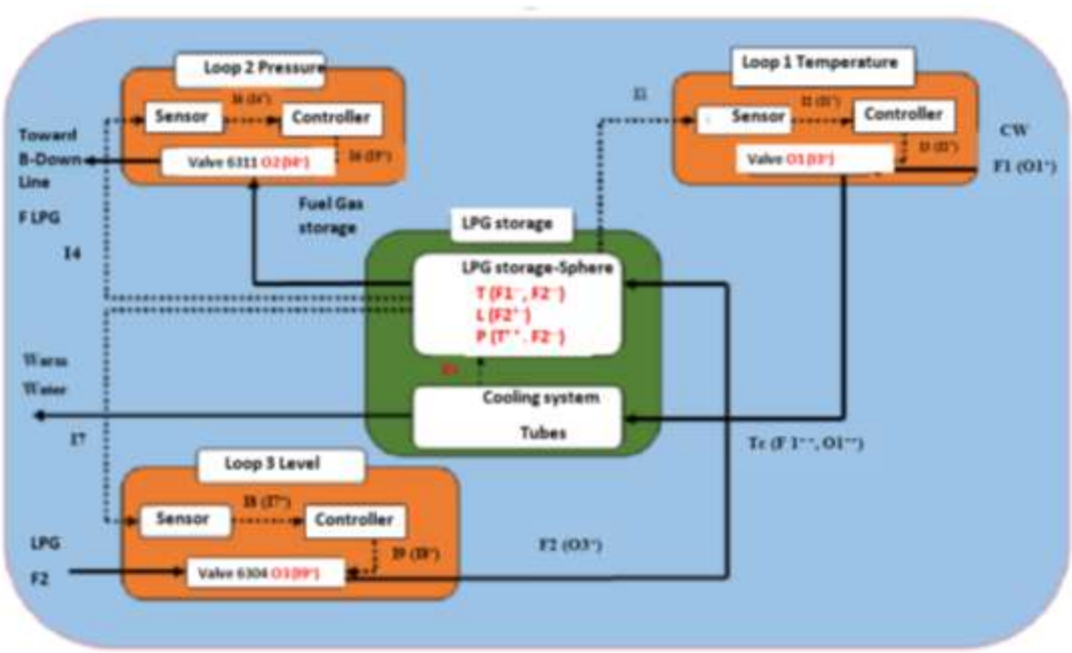

Figure 5. *D-HIGRAPH model for S-151*

The pressure inside the sphere is controlled by loop 2 through the opening/closing O2 of valve 6311which is connected to Blowdown line (flare system) for discharging.

The above process variables interact with each other via the qualitative physics constraints F++, T++and L++ etc.

Such that:

$T(F1^{--})$ Means that the temperature inside the sphere will increase whenever the flow F1 decreases and decreases whenever F1 increases, F1 is controlled via the opening of valve O1.

$L(F2^{+-})$ Means that the level in the sphere will increase whenever the LPG flow F2 increases and the level still increasing (with small amount) whenever the LPG flow decreasing.

The causal trees shown in Figures 7 summarize the interactions between the different parameters such that:

dec is the abbreviation of decreasing whereas inc is for increasing.

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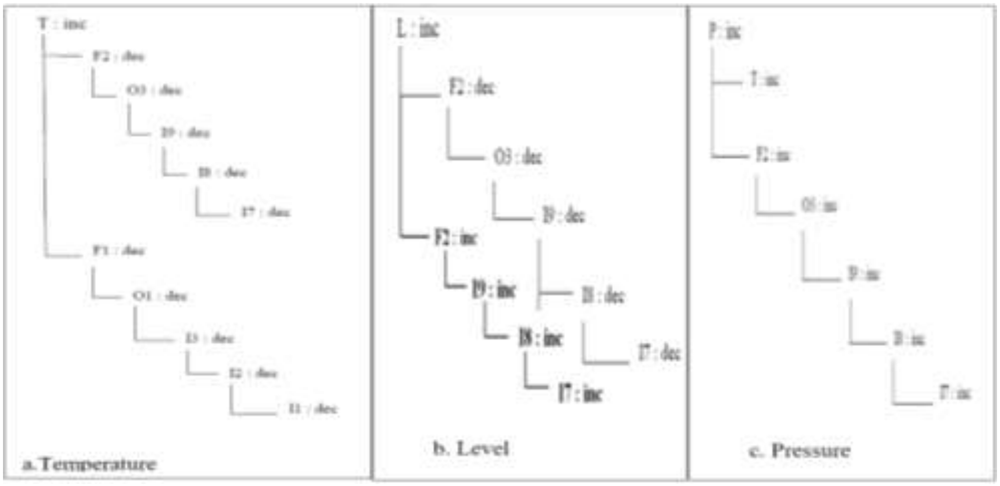

Figure.7. *Causal tree of the sphere deviations*

Figure 7.a concerns the causal tree of the deviation in the sphere temperature. It can be interpreted as follows: the sphere temperature is higher than its expected value (T: inc) this is due two main causes:

The first is Lower flow of LPG (F2: dec) caused by the lower opening of the valve (O3: dec) which resulted from a bad signal coming from the sensor (I8:dec) or bad control action signal (I9:dec) or sensor fail situation (I7:dec).

The second is lower flow of cooling water (F1:dec) which is caused by a malfunction of valve O1 to open (O1:dec), caused by a bad signal of the measured value (I2:dec), a control action bad signal (I3:dec) or sensor fail (I1:dec).

Figure 7.b shows the causaul tree, of the deviation in sphere level (the case where it is higher than the expected value (L:inc)) , which may be caused by (F2: Inc) due to the malfunction of valve (O3:inc) to open more, which can be caused by malfunction in the controller (control action bad signal I9:inc) or sensor malfunction (bad signal to controller I8:inc or sensor fail I7:inc).

Another way of causing (L:inc) is F2:dec .

Figure 7.c shows the pressure causal tree (P: inc) which is in direct interaction with the the previous parametrs for temperature and level.

III.3 HAZOP sheet for node LPG storage

The Hazop report is very long since we examine all the possible situations using the key words,the most dangerous situation deduced from HAZOP report is indiacted in Table 1. Which represents the case of high pressure in the sphere, this situation may be caused by the malfunction to fully closed of the ROV –in the sphere's inlet. It is considered as the most dangerous scenario since it may affect not only the sphere but also the environment and persons in a long distance far from the industrial zone. It should be mentioned that the HAZOP causes and consequenses included in the long HAZOP report could be represented by simple causal tree of D-HIGRAPH model.

Table 1. *HAZOP sheet Node sphere S-151*

GW	Parameter	Deviation	Causes	Consequences	Safe guards	Recommendation
More	Pressure	1. High pressure	1.1 Malfu-ction that prevent the fully closing of the ROV	1.1.1.Possible explosion due to high pressure and sphere life duration (BLEVE event) 1.1.2.Harms in the nearby sphere and bullets 1.1.3. Damage in the sphere body. 1.1.4.Damage in the installed instruments and systems 1.1.5.Pollution due to the product dispersion 1.1.6.Leakage in the joints and flanges	PAHH 6103 high high pressure alarm - Interlock that closes the ROV and open the valve to blow down line - PSV - Gas detector for fire and gas system - Fire water system	

III.4. ALOHA simulation

In this section, a simulation for the deduced dangerous scenario is realized. Table 2 summarizes the input data loaded to ALOHA to proceed with the simulation.

Table 2. *Simulation input data*

Site	Skikda, RA1K, Melex, ALGERIA
Chemical data	Name : Butane, Molecular wiegth: 58.12g/mol. LEL:16000 ppm (lower explosion limite) , UEL:84000 ppm (upper explosion limit) Ambient boiling point :-0.6 ^{o}C (the above data are already specified in the data base of the software)
Atmospheric data	Wind:3meters/sec from NE (north east) at 10 m. Air temperature: 22^{o}C. Relative Humidity :70%
Tank data	Spherical tank Diameter : 19.2 m Volume: 3706 cubic meter Chemical mass in tank : 1.890 ton Tank is 80% full

The following aspects are considered during the simulation

III.4.1 Thermal effect with respect to explosion

Figure 8 divides the threated zones depending on the explosion strength the red zone is the most dangerous, the orange is the second, and the last is the yellow one. The exact mapping of the threat zones in a real map (google map) is shown in Figure 9.
Table 3 summarizes the infected facilities sucth that the contour thresholds are defined following National fire protection association standard NFPA-95 [29].

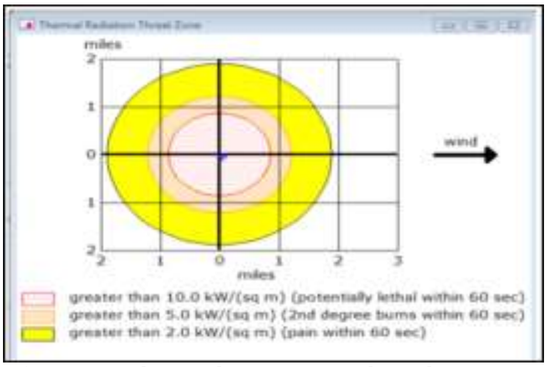

Figure 8. *The explosion strength with respect to distance*

Figure.9. *The exact location of threated zones (google map)*

Table 3. *The infected zone by the explosion*

The strength	Threat zones
10 KW/M^2	RA1K plant, the buildings near the road Cw21 (CW: wilaya road) companies offices….)
5 KW/M^2	RA1K and It will be extended to reach more plants such as CP2K (plastic complex) and Terminal RTE and the east side of CP1k. moreover it will reach the building near the CW21 road.
02KW/M^2	Here it will include all the previous plants and buildings in addition to the east side of GL1K (complex of liquified gas) and the seaside road LARBI BEN MHIDI.

III.4.2 Release of toxic and pollutant materials

Figure 10 shows the dispersion of pollutant materials following an explosion in the area near the tank. Whereas Figure 11 indicates the exact location in the refinery map.

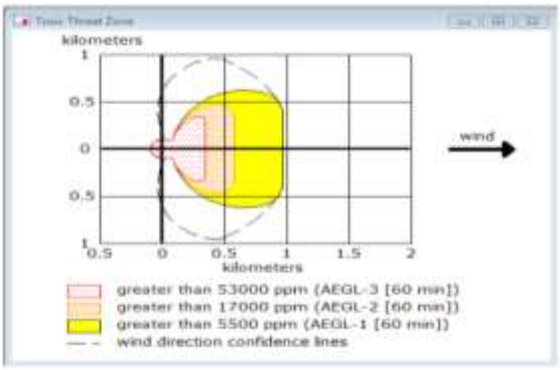

Figure 10. *Toxic zone following the dispersion of a vapor cloud*

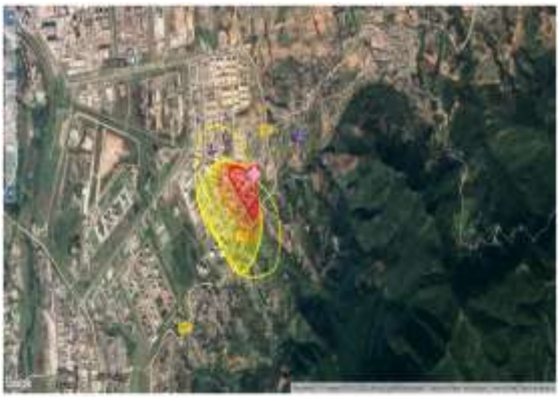

Figure 11. *Toxic zones following the dispersion of pollutant materials mapped on RA1K map.*

Table 4 summarizes the infected facilities by the diperssion of toxic materials for the different zones.

Table 4. *The infected zone by the vapor cloud*

The strength	Threat zones
53000 PPM	Storage tanks east zone near the sphere. The DRIK (industrial zone Skikda) fence near the road Cw21
17000 PPM	Storage tanks in the east area and in the south zone. Moreover, it will reach the habitation (Site called BAREAUX) near the CW21 road.
5500 PPM	Storage zone in the east and south to areas till the storage area of RA2K, reforming unit (unit 103) , south part of the unit 11, the east part of the adaptation access, moreover it will reach the habitation of BAREAUX near the CW21 road

The following figures (Figure 12 -15) show the concentration of the pollutant materials in the limits of the differnt zones.

The red zone is extended to a diatance of 340 m. The maximum concentration is 1 000 000 ppm at the start point (the explosion center)

At the point 340 m the concentration is 60000 ppm (this can be detected after 3 minutes from the release starting).

The orange zone is extended to a distance of 580 m and the concetration will be 17000 ppm (the gas may be detected after 5 minutes from the release starting).

The yellow zone is extended to a distance of 960 m and the concentration is 6000 ppm (the pollutant will be detected after 7 minutes from the release starting).

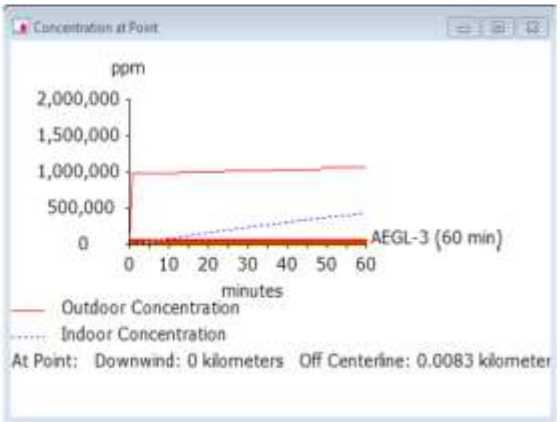

Figure 12. *the pollutant concentration at the center.*

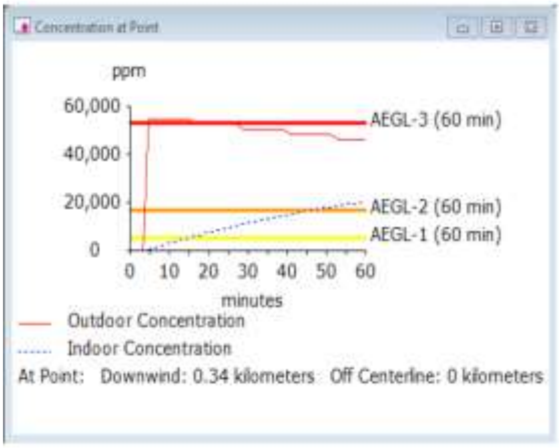

Figure.13. *The pollutant concentration at the point (340 m, 0)*

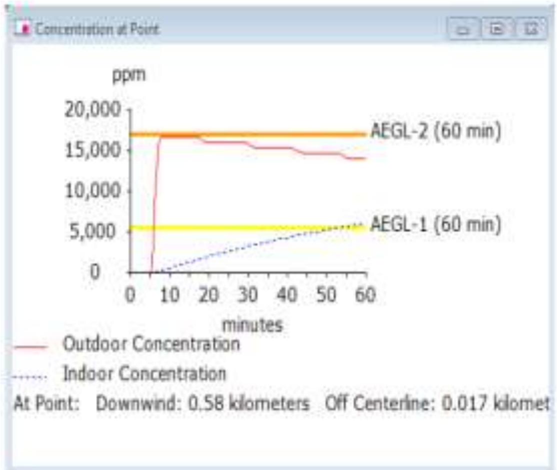

Figure 14. *The pollutant concentration at the point (580 m, 0)*

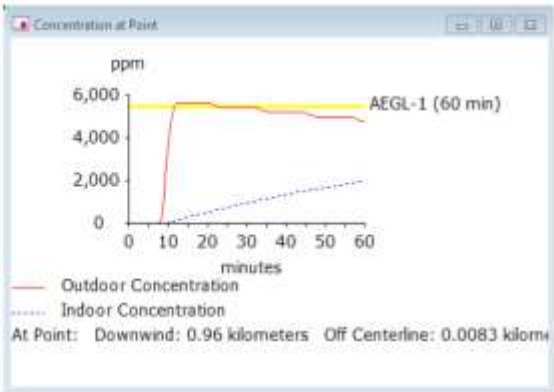

Figure 15. *The pollutant concentration at the point (960 m, 0)*

III.4.3 Release of flammable materials

In this case, only two threat zones as it is indicated in Figure 16. The red one is the most dangerous, which is extended at distance of 750 m, the yellow is the second; it extends at a distance of 1750 m. In Figure 17 the exact localization of each threat zones in the refinery map are presented.

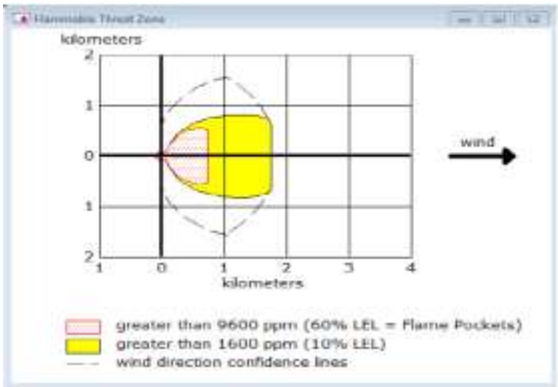

Figure 16. *Dispersion Areas of the flammable cloud*

Figure 17. *Dispersion Areas of the flammable cloud mapped on the RA1K map*

The equipment and facilities that may be affected by the explosion are summarized in table 5.

Table 5. *The infected zone by the flammable cloud*

The strength	Threat zones
9600 PPM	RA1K plant, the habitation near the road Cw21 (companies offices….), and the storage zone in the south
1600 PPM	Here it will include all the previous plant and road in addition to the tanks of RA2K and the RTE.

The Figures (18-20) show the concentration of the flammable material in the boundary limits of each zone.

In the center the concentration is almost equal to 1000000 ppm then it decreases to 60000 ppm at the point (720m, 0) , and decreases to reach 1600 ppm at the point (1750m, 0).

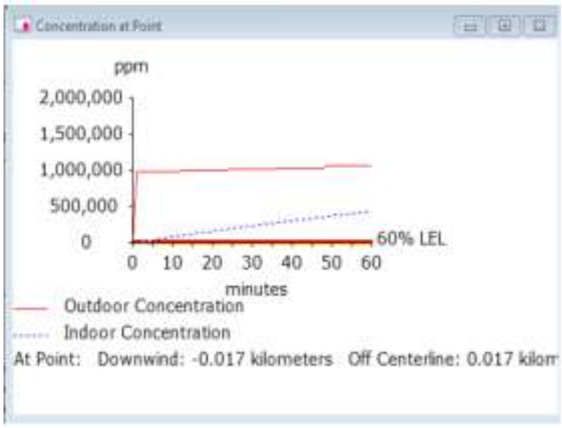

Figure 18. *Flammable concentration at the center (0, 0)*

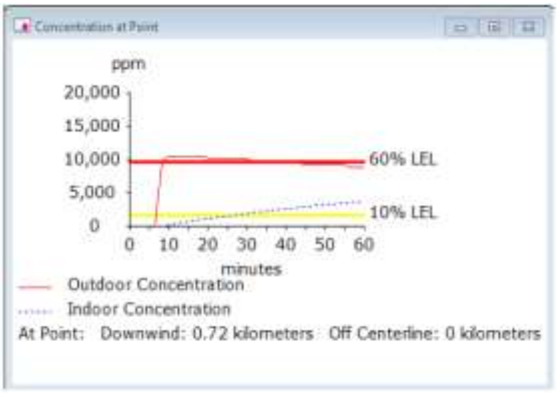

Figure 19. *Flammable concentration at the point (720 m, 0)*

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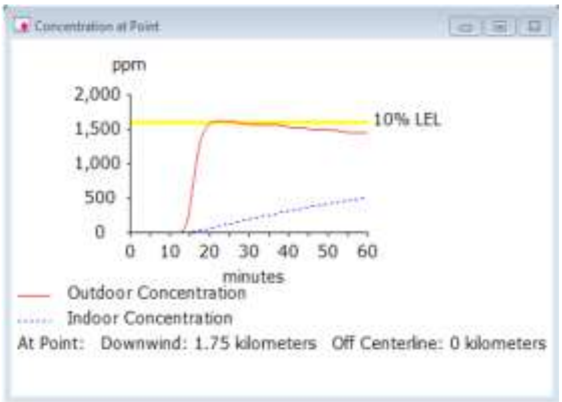

Figure 20. *Flammable concentration at the point (1750 m, 0)*

IV. Conclusion

The aim of our study is to present a systematic methodology to identify and reduce the potential risks in an LPG storage area located in Skikda refinery Algeria.
To achieve this goal the following operations have been performed:
1. An effective and simple graphical model based on D-HIGRAPH – is presented the model shows the different control loops and their interactions, the model gives a clear description for the complexe system, and helps in extracting the exact causes for any possible abnormal situation.
2. A deep HAZOP study where all expected scenarios are tested using guid words and deviations. Each possible deviation is examined by identifying its causes and consequences and in the same time the existing safeguards used to mitigate the possible scenarios, in case the existing safeguards are not sufficient to perform the job, recommendations to add another safety measures should be raised.
3. From the previous steps we deduce that the most dangerous scenario is an explosion that may happen because of a high pressure in one of the spheres or the bullets of the area. The simulation of the impact of this dangerous scenario on the environement is realized using ALOHA software. The simulation covers the following aspects: the explosion thermal effecs where the exact threat zones are shown in the refinery map (the map is given by Google map software), each zone corresponds to a specific explosion strength, the second aspect, is the release of toxic materials. Similar to the previous case the threat zones marked on the refinery map depending on the concentrations of the pollutant dispersion, the concentration of the polluatant in the limit of each zone is defined. The third aspect is dispersion of flammable materials in the area near the refinery.
We should mention that the above simulation is realized in one sphere S-151; the same remarks can be generalized for the other spheres or bullets. From the simulation, we conclude that special safety measures should be considered because in case any deviation it will cause dangerous accidents that may affect the materials, the persons's health and the environment not only in the industrial zone but the effcts may be extended to reach the nearby habitation (Site called BAREAUX) near the CW21 road.
As a recommendation to insure a safe operation in the storage area and the plant in general, additional studies based on socio-technical studies STAMP-STPA should be performed and high safety integrity level systems should be acquired.

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