Functional modeling using D-higraph for process hazard analysis

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Abstract: The main objective of this paper is presenting the use of D-higraph to perform hazard analysis. D-higraph is a functional modeling technique; it is used to capture the functional and structural aspects of process plants. It presents not only the functionality of the system with its goals, but also the relation existing between these functions/goals and the devices that perform/achieve them. This work is applied to the study of an industrial case in a petroleum plant in Skikda refinery.

Keywords*:* HAZOP; D-higraph; Functional modeling; Causal tree; Risk assessment.

1. INTRODUCTION

There are a lot of important aspects involved in the consequences of accidents: environmental impact, pollution, operators' occupational health and economy. Avoiding accidents saves money because the losses associated to shutdowns, reparations, compensations or fines are reduced. At the same time, incomes are increased because productivity does. The other aspects also benefit from a safe operation [1].
Process Hazard Analyses (PHA) are carried out to identify the potential safely problems of a process plant in order to provide possible solutions such as process changes, new control strategies or the use of safety instrumentation. There are a broad variety of methods but the most widely used are HAZOP studies [2]. However, they consume a lot of time an effort so in the last decades a lot of work and resources has been put to find alternatives to this process.
In this work a HAZOP study is performed based on the D-higraphs methodology, which considers structural and functional information of the system under analysis. Besides, this approach takes into account in a natural way the process itself together with its control system.

2. HAZARD AND OPERABILITY (HAZOP)

A HAZOP study is a highly disciplined procedure that identifies how a process may deviate from its design intent [3]. It is a structured analysis of a system, process, or operation for which detailed design information is available, carried out by a multidisciplinary team. This is done by using a set of guidewords in combination with the system parameters to seek meaningful deviations from the design intention. A meaningful deviation is one that is physically possible—for example, no flow, high pressure… It's a method used for hazard identification [4]. HAZOP is one of the process hazard analysis techniques [5]. It is a systematic examination of a process or operation [6], the primary purpose of HAZOP study is to identify and evaluate hazards [7]. In addition, recommendations to reduce the probability and consequences of an incident should be offered [8].

Table.1. exemple of HAZOP worksheet [9]

1	2	3	4	5	6	7	8
Guide word	Parameter	Causes	Consequences	Détection	Safe guards	recommendations	Comments

3. FUNCTIONAL MODELING

Functional Modeling is an approach used to model any man-made system by identifying the designer defined overall goal it must achieve and the designer/user defined functions it must perform [10].
Functional Modeling comprises concepts, methods and tools for representing the purposes and functional organization of complex dynamic systems [10].

4. D-HIGRAPH

D-higraph is a functional modeling technique [3, 11, 12, and 13]; the key idea of a D-higraph is to capture the functional as well as the structural aspects of process plants [11, 13]. In other words, the aim of a D-higraph model is to gather activity and ontological features of the system modeled in an integrated model [11]. A tool to perform a semi-automatic guided HAZOP study on a process plant is presented. The diagnostic system uses an expert system to predict the behavior modeled using D-higraphs [12]. D-higraphs is not only the representation of knowledge about process systems. There are a series of causation rules implemented that provides relating two events which allows us to track the evolution and propagation of failures across the system [14].

- Blobs and Edges

Blobs and their basic elements are depicted in the left-hand-side of Figure 2 and the different types of edges are shown in the center of Figure 2. Blobs represent functions (transitions) that are performed by an ACTOR producing state/s 2 if the state/s 1 is enabled and if the condition is true. Edges represent flows of mass, energy, or information, which are responsible of all the interactions in a process system [15]. Mass, energy and information edges are depicted differently, but the type of flow does not affect the behavior of the model, it is a just a visual aid [1].

The main properties of blobs and edges are:

• Blob connection. An edge always links two blobs. Under certain conditions, one of the blobs cannot be represented (elliptic blob), but it exists.

• Blob inclusion. Blobs can be included inside of other blobs (Venn diagram inclusion). This means that the inner blob performs a function that is necessary for the function of the outer blob (representation of functions hierarchy).

• Partitioning blobs. A blob can be partitioned into orthogonal components, establishing an OR condition between the partitions.

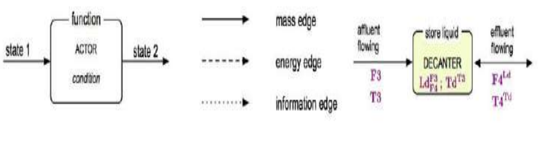

Figure.2.Basic blob and different types of edges [1].

5. CAUSAL TREE

The main objective of D-higraphs is not only the representation of knowledge about process systems. There are a series of causation rules implemented that provides relating two events which allows us to track the evolution and propagation of failures across the system. These rules, combined with sensor data of the plant. In a certain way, we need to simulate qualitatively the system in order to propagate deviations. These deviations are represented summarized in a causal tree. So the D-higraph is not only a tool of modeling but it has two other objectives, the causal reasoning and the qualitative simulation.

6. FUNCTIONAL DESCRIPTION OF THE STUDIED PLANT: SPLITER-I

In this study the plant concerned is a Naphta stabilizer-A reflux drum (Figure 1) [16], located at crude oil unit in Skikda refinery (Algeria).

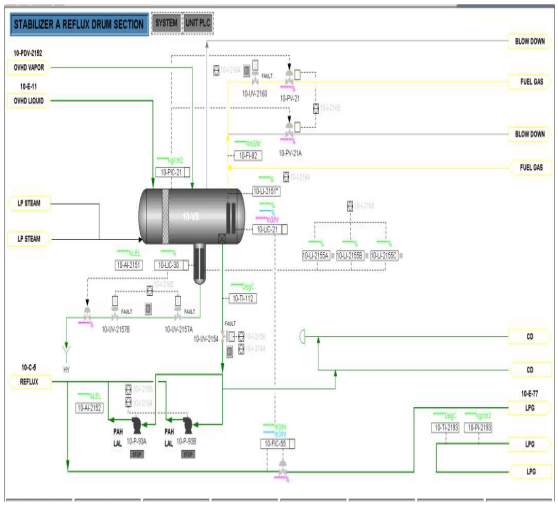

Figure.1. Diagram related to the Naphta Stabilizer-A Reflux Drum [16]

The vapors of column C-5 overhead are condensed in air cooler Stabilizer-A Overhead Product Condenser (EA-2A~G), and Stabilizer-A Overhead Trim Condenser (E-11), and then collected in accumulator Stabilizer- A Reflux Drum (V-8). The reflux drum is operated at temperature and pressure condition of 43°C and 7.0 kg/cm2 g. Pressure in the reflux drum V-8 is controlled by PIC-21 acting in "split control" on valves PV-21 and PV-21A. Uncondensed vapor fuel gas flow is controlled through PV-21 and further incondensable materials accumulated in stabilizer-A Reflux Drum (V-8) can be discharged to the blow-down through PV-21A. The liquid which is accumulated in the receiving tank of overhead V-8 is sucked by pumps MP-93A/B at the temperature indicated by TI-112 and sent partly to the overhead of column C-5 as reflux under flow controlled of FIC-53 through flow control valve FV-53 and partly constituting the production of column overhead in unit 30 with the flow rate controlled by FIC-55 operating in cascade with level controller 10-LIC-21, equipped with alarm for low level LAH/LAL-21. Interface level between LPG and oily water in V-8 is controlled by LIC-30 by controlling flow through LV-30 located in discharge line of boot. As an extra safety hydrocarbon detector AI-2151 and AI-2152 has been provided near the reflux drum (10-V-8) bottom and reflux pump (MP-93 A/B). Further as a part of safety LI-2151 has been provided with High-High and Low-Low level alarm LAHH-2151 & LALL-2151. In case of LAHH-2151 interlock I-2164 will get actuated and UV-2160 in the overhead line of 10-V-8 will get closed. In case of LALL2151 gives signals the interlock I-2164 will get actuated and close the on- off valve UV2154 installed in the suction line of MP-93 A/B. For the boot level another interlock I-2165 will be actuated by LALL55 A/B/C (2oo3 voting logic) to close UV-2157 A/B in order to protect LPG leaking [16].

Table.2.Different safety systems protecting stabilizer-A reflux drum [16]

Safety systems	Landmark	Description
Pressure Safety Devices	PSV-50	Starting pressure 9.8 kg / cm^2g
	PV-21	Discharge To FG line
	PV21A	Discharge To Blow down
Interlocks	I-2156	Activated by HS-2154A/B and Action on: Close UV-2154 Stop pump MP93
	I-2164	Activated by LT/LAHH-2151 Action on: Close UV-2160. Close PV-21. Open PV-21A
		Activated by LT/LALL-2151 and Action on: Close UV-2154 Stop Pump P-93A/B
	I-2165	Activated by LT/LALL-2155A/B/C Action on: Close UV-2157A/B
Alarms	PAH-21	V-8 Pressure 7.7 kg/cm2g
	PAL-21	V-8 Pressure1.1 kg/cm2g
	LALL-2151	V-8 Level 300 mm
	LAHH-2151	V-8 Level 1705 mm
	LALL-2155	V-8 Root Level 230 mm
	LAL-21	V-8 Level 300 mm
	LAH-21	V-8 Level 1450 mm
	LAL-30	V-8 Interface Level 290 mm
	LAH-30	V-8 Interface Level 470 mm
	FAL-55	LPG Flow (MP-93 A/B) 39 m3/hr
Gas detectors	10-AI-2151	near the reflux drum (V-8) bottom
	10-AI-2152	Near reflux pump (MP-93 A/B)

7. HAZOP RELATED TO THE STUDIED PLANT (NAPHTA STABILIZER-A REFLUX DRUM)

In the studied system, we applied HAZOP on some parameters just to give examples, so we Chose less level of LPG in the drum, and less level of oily water in the boot as deviations.

Table.3. HAZOP Analysis "no level of LPG" and "no level of oily water" related to reflux drum V-8

deviation		Causes	Consequences	Warnings	Protection means
parameter	Guide word				
Level of LPG in V8	NO	- Insufficient cooling of overhead vapor due to EA2 and E11 failure. - BPCS of LPG level failures: LT 21 failures LIC 21 failures FIC 55 failures FV 55 failures (does not close) - BPCS of LPG flow failures: FT 55 failures FIC 55 failures FV 55 failures (does not close)	- cavitations of MP 93 - gas leaking - fire - UVCE	- Alarm LAL on LIC 21 - Alarm LALL on LIC 2151 - Alarm AAH on AI 2152	- Interlock 2156 (close UV 2154 and stop pump MP 93) - Interlock 2164 (close UV 2154 and stop pump MP 93)
Level of oily water in boot	NO	- BPCS of oily water level failures: LT 30 failures LIC 30 failures LV 30 failures (does not close)	- gas leaking - jet fire - pool fire - UVCE	- Alarm LAL on LIC 30 - Alarm LALL on LIC 2155 - Alarm AAH on AI 2151	- INTERLOCK 2165 (CLOSE UV 2157 A/B)

8. D-HIGHGRAPH OF THE PROPOSED SYSTEM (NAPHTA STABILIZER-A REFLUX DRUM)

In D-higraph, the hierarchy of functions/goals is presented in terms of blobs inclusion and the dependences between them in terms of edges connecting the blobs. The D-higraph models the process elements of the system but it also includes the control system elements.

Figure.3.D-highraph of the proposed system (Naphta Stabilizer-A Reflux Drum)

9. DEVIATIONS CAUSAL TREES

To present causal trees we chose four critical deviations in the studied system (less level of LPG in the drum, less level of oily water in the boot, high pressure in the drum and high temperature in the drum.

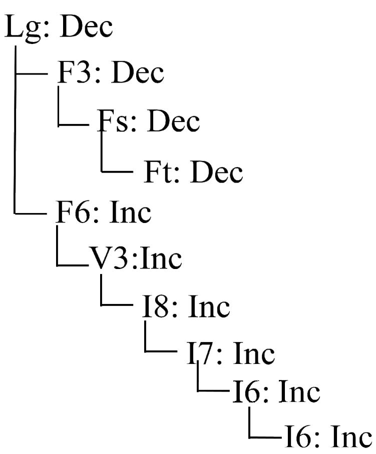

Figure.4.Causal tree of deviation Lg: dec (less level of LPG in the drum)

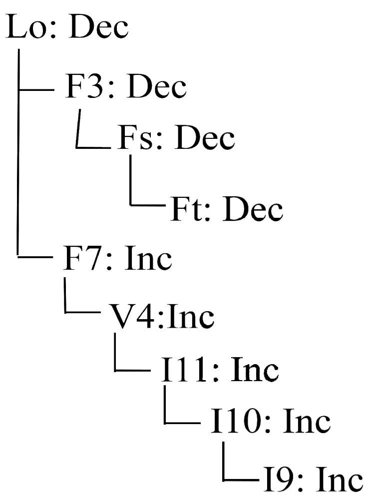

Figure.5.Causal tree of deviation Lo: dec (less level of oily water in the boot)

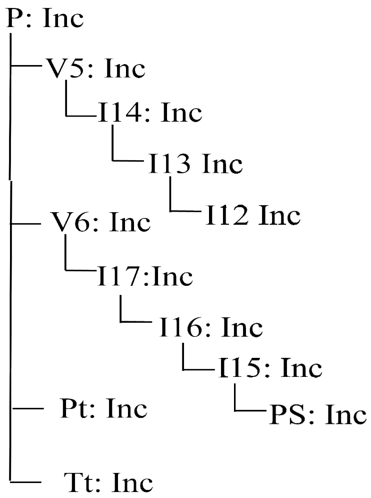

Figure.6.Causal tree of deviation P: inc (high pressure in the drum)

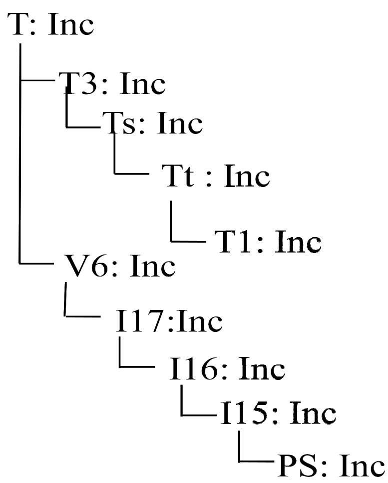

Figure.7.Causal tree of deviation T: inc (high temperature in the drum)

10. DISCUSSION

The use of D-higraph allowed us to capture a functional and dysfunctional model of HAZOP study; this model presented the relation between different elements and the interaction of deviations.

Deviation 1: less level of LPG in the drum

This deviation corresponds with the variable “less level of LPG in the drum (Lg)” and HAZOP guide word “Less”. According to d-higraph represented in Figure 3, the causal tree obtained is shown in Figure 4, this tree is a translation of process variables. The level of LPG in the drum (Lg) is less than expected could be caused by low flow of LPG to the drum (F3: Dec) or high flow of the LPG to the Stripper (F6: Inc). The low flow of LPG to the drum could be motivated by low flow from the condenser (Fs: Dec) which is caused by a low flow from the Stripper (Ft: Dec). The high measured flow of the LPG to the Stripper could be caused by operation the valve more than it should be (V3: Inc) and it is caused by high control signal to the valve (I8: Inc), caused by high level control signal (I7: Inc), caused by high measured level in the drum (I6: Inc) or (I5: Inc).

Deviation 2: less level of oily water in the boot

This deviation corresponds with “less level of oily water in the boot (Lo)” and HAZOP guide word “less”. According to d-higraph represented in Figure 3, the causal tree obtained is shown in Figure 5. The level of oily water in the boot (Lo) is less than expected could be caused by low flow of LPG to the drum (F3: Dec) or high flow of the oily water to the open drain (F7: Inc). The low flow of LPG to the drum could be motivated by low flow from the condenser (Fs: Dec) which is caused by a low flow from the Stripper (Ft: Dec). The high measured flow of the oily water to the open drain could be caused by operation the valve more than it should be (V4: Inc) and it is caused by high control signal to the valve (I11: Inc), caused by high measured level in the boot (I10: Inc) or (I9: Inc).

Deviation 3: high pressure in the drum

This deviation corresponds with “high pressure in the drum (P)” and HAZOP guide word “more of”. According to d-higraph represented in Figure 3, the causal tree obtained is shown in Figure 6. The pressure is higher than expected could be caused by high temperature (Tt: Inc), high pressure (Pt: Inc) in the Stripper or operating pressure regulating valves more than they should be (V5: Inc and V6: Inc). The more opening of pressure valve is cause by high control signal to the valve (I14: Inc), caused by high measured pressure (I13: Inc). The high measured pressure could be caused by high pressure seen in the Stripper head (I12: Inc). The more opening of difference pressure valve is cause by high control signal to the valve (I17: Inc), caused by high measured difference pressure between the Stripper head and the drum (I16: Inc). The measured difference pressure could be caused by high pressure seen in the Stripper head or less pressure seen in the drum (I15: Inc) and (Ps: Inc).

Deviation 4: high temperature in the drum

This deviation corresponds with “high temperature in the drum (P)” and HAZOP guide word “more of”. According to d-higraph represented in Figure 3, the causal tree obtained is shown in Figure 7. The temperature is higher than expected could be caused by high temperature of LPG from the condenser (T3: Inc) or operating difference pressure regulating valve more than it should be (V6: Inc). The more opening of difference pressure valve is cause by high control signal to the valve (I17: Inc), caused by high measured difference pressure between the Stripper head and the drum (I16: Inc). The measured difference pressure could be caused by high pressure seen in the Stripper head or less pressure seen in the drum (I15: Inc) and (Ps: Inc). The high temperature of the LPG from the condenser is caused by the high temperature in the shell (Ts: Inc), which is caused by the high temperature in the tubes (Tt: Inc). The high temperature in the tubes could be caused by the high temperature of the cooling water (T1: Inc).

11. CONCLUSION

In this paper we have presented a tool to perform systematic guided HAZOP studies based on D-higraphs, a functional modeling technique that merges functional and structural information. To show its applicability we have analyzed an industrial process.
Conventional HAZOP studies are systematic and a logical way of performing PHA. However, a lot of time is devoted to routine

deviations. The automation of the procedure saves time. Using D-higraph to perform HAZOP, the team can spend their time in analyzing the deviations, causes, consequences and the possible solutions and not in obtaining them.
Another advantage of using D-higraph is that no nodes are left unexplored. We only need a model (a D-higraph) of the process and not a model for each node of the HAZOP analysis.

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