People’s Democratic Republic of Algeria
Ministry of Higher Education and Scientific research
M’hamed Bougara University, Boumerdes
Institute of Electrical and Electronic Engineering,
Laboratory of Signals and Systems (LSS)

ALGERIAN JOURNAL OF SIGNALS AND SYSTEMS

ISSN : 2543-3792

Title**: Automated dependability analysis of the HDPE Reactor using D-higraphs HAZOP assistant**

Authors: **El-Arkam MECHHOUD(1)*, Manuel RODRIGUEZ(2), Youcef ZENNIR(3)**
Affiliations**:**
(1)(3) Dept. electrical engineering, Université de 20 Août 1955 (LAS), Skikda, Algeria
(2) Dept. chemical engineering, Polytechnical University (ASLAB), Madrid, Spain

Page range: **255- 265**

Volume : 2 Issue : 4 (December 2017)
A special issue of the International Conference on Advanced Engineering in Petrochemical Industry (ICAEPI’17)
November 28-30, 2017, Skikda, Algeria

Laboratory of Signals and Systems
Address : IGEE (Ex-INELEC), Boumerdes University, Avenue de l’indépendance, 35000, Boumerdes, Algeria
Phone/Fax : 024 79 57 66
Email : lss@univ-boumerdes.dz ; ajsyssig@gmail.com

ALGERIAN JOURNAL OF SIGNALS AND SYSTEMS (AJSS)

Automated dependability analysis of the HDPE Reactor using D-higraphs HAZOP assistant

El-Arkam MECHHOUD(1)*, Manuel RODRIGUEZ(2), Youcef ZENNIR(3)
(1) dept. electrical engineering, Université de 20 Août 1955 (LAS), Skikda, Algeria
(2) dept. chemical engineering, Polytechnical University (ASLAB), Madrid, Spain
(3) dept. chemical and petrochemical engineering, Université de 20 Août 1955 (LAS), Skikda, Algeria
* elarkam_mechhoud@yahoo.fr

Abstract: In this paper we present a HAZOP Assistant based on D-higraphs and dedicated to a functional modeling technique that gathers functional and structural information of the process under study. This work is applied to the study of an industrial case - High Density Polyethylene reactor part of the CP2K plant situated in the petrochemical platform of Skikda- and its results are compared with the conventional HAZOP study and SADT method.

Keywords: Risk assessment, HAZOP, D-higraph, DHA, HDPE.

1. INTRODUCTION

Process plants (refineries, chemical plants, petrochemical, etc.) deal with a large amount of potentially dangerous materials (toxic, inflammable, explosive) and many times in extreme conditions (such as high temperatures and pressures). This can lead to equipment failures, plant shutdowns or even worse accidents with catastrophic consequences.

Traditional hazard analysis techniques, such as failure modes and effect analysis (FMEA), Hazard and operability (HAZOP), and fault tree analysis (FTA) have been used for a long time; they are not well-suited to handle modern systems with complex software, human- machine interactions, and decision-making procedures.

Many research works present automated tools for risk analysis and assessment exist in the world such as a TORAP, a HAZOPExpert, PHASuite, Functional HAZOP assistant, Automating HAZOP studies using MFM.

HAZOPExpert (HE) is a model-based, object-oriented, intelligent system consisting of two different knowledge bases: process specific and process general knowledge. HE and D-higraphs HAZOP assistant are similar approaches to the PHA problem—model-based, object oriented, intelligent systems—but the methodology presented in this paper incorpo-rates an additional feature that HE does not: functional information. Multilevel Flow Modeling (MFM) is used to represent the knowledge of the process combining meansend and whole-part dimensions (Lind, 1994). The MFM HAZOP Assistant needs a MFM model for each node which is developed according to the node main objective. Using the D-higraph methodology, only an overall model is needed. To perform the analysis we only need to indicate the desired deep in terms of causality propagation. This issue saves even more time and enables the disturbances and deviations to propagate through the whole system (if desired).

In order to conduct an automated risk assessment we are using the functional system modeling (D-higraph) assistant by HAZOP studies. We are applying this methodology on HDPE reactor, which is situated in CP2K- Skikda- plant.

2. HAZARD AND OPERABILITY STUDY (HAZOP)

A HAZOP study is a highly disciplined procedure that identifies how a process may deviate from its design intent [12]. It is defined as the application of a formal, systematic critical examination of the process and the engineering intentions of new or existing facilities to assess the malfunctioning potential of individual components of an equipment, and the consequential effects on the facility as a whole. This method‘s success lies in its strength in analyzing system‘s Piping & Instrumentation Diagrams (P&IDs), breaking the design into manageable sections with definite boundaries called nodes, so as to ensure the analysis of each equipment piece in the process [1]. A small multi-disciplinary team undertakes the analysis, whose members should have sufficient experience and knowledge to answer most questions on the spot. The members are selected carefully, and are given the authority to recommend any needed changes in the design [2]. Executing the method relies on using guidewords (such as no, more, less) combined with process parameters (e.g., temperature, flow, and pressure) that aim to reveal deviations. These deviations result from the combination of a 'guide word' with a 'property'of the line: guideword + Parameter = Deviation (such as less flow, more temperature) [3]. Having determined the deviations, the expert team explores their possible causes and their possible consequences [4]. HAZOP is useful to apply to systems that involve human performance and behavior or to systems that involve hazards that are hard to quantify or detect. On the other hand, HAZOP does not take into account human errors. Thus, HAZOP analysis procedure is basically standardize, there is an IEC for it, but as it relies on people analysis different teams can come up with different results worldwide; hence, the analysis is performed differently with variation in results for the same system [5]. Moreover, HAZOP study does not take into account the interaction between different component in a system or a process [6], and it also can be lengthy and expensive [7]. However, HAZOP is time consuming. According to one evaluation [8], for a process with many P&ID ranging, a team of five people led by an experienced team leader needs more than 400 man hours for the finalization of the HAZOP analysis, and the overall spent time is about 8 weeks. So an automated analysis is helpful in reducing time, minimizing the errors and can be used as an aid for human expert.

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 (Modarres, 2004) [9]. Functional Modeling comprises concepts, methods and tools for representing the purposes and functional organization of complex dynamic systems (Lind, 2007) [9].

Graphs

A graph is an abstract representation of a set of objects where some pairs of the objects are connected by links. The interconnected objects are represented by mathematical abstractions called vertices, and the links that connect some pairs of vertices are called edges. Graphs are so named because they can be represented graphically and is this graphical representation which helps us to understand many of their properties. There is no unique way of drawing a graph. The relative positions of vertices and edges have no significance (Bondy and Murty, 1976) [9].

Digraphs

A digraph (directed graph) is a pair where is the set of vertices and □ is a set of ordered pairs of vertices, called arcs or directed edges. Both kinds of graphs —Graphs and Digraphs— differ in the set of edges; in graphs they are unordered pairs while in digraphs are ordered pairs. Hence, directed graphs or digraphs are oriented graphs, i.e., conventional graphs with oriented edges (Diestel, 2005) [9].

Venn Diagrams and Euler Circles

Venn Diagrams and Euler Circles are schematic diagrams used to depict collections of sets and represent their relationships. The intersection of the interior of a collection of curves and the exterior of the rest of the curves in the diagrams is called a zone. Thus, in Venn diagrams all zones must be present (given the set of curves), but in an Euler diagram some zones might be missing (Ruskey and Weston, 2005) [9].

Higraphs

Higraphs are a combination and extension of graphs and Euler-Venn diagrams, so it is a visual formalism. They were first presented in (Harel, 1988) and extended in (Harel and Gery, 1997). They are formed by modifying Euler-Venn diagrams extending them to represent Cartesian products and connecting the resulting 'blobs'by edges. They constitute a visual formalism of topological nature that can represent set enclosure, exclusion and intersection and the Cartesian product [10].

Higraphs consist of two elements:

- Blobs: They are represented as rounded-corner rectangular shapes representing mutual exclusive sets and may intersect and be arranged in an inclusion hierarchy. Blobs of different hierarchy levels can be connected.
- Edges: They are represented as arrowed (directed) lines and are used to connect blobs.

D-higraphs

D-higraphs are an adaptation (dualization) of Higraphs. The main difference lies in the interpretation of these properties. In Higraphs, disjoint blobs mean that there is an OR relation between them, while the AND relation is represented by orthogonal blobs. On the other hand, in D-higraphs we interpret them the other way around, i.e., disjoint blobs imply an AND relation while orthogonal blobs represent an OR relation. This dualization of Higraphs is gathered in Table 1[11].

Table 1 Dualization of higraphs.

Blobs	**Higraphs**	**D-higraphs**
Disjoint	OR	AND
Orthogonal	AND	OR

D-higraph is not a dual higraph (like dual graphs), obtained from changing blobs by edges and edges by blobs. The duality lies in the interpretation of blobs, edges and their properties.

Blobs: Blobs represent functions and they are depicted as shown in Figure 1.The name of the function appears in the border of the blob, and the actor (usually an equipment or device) that performs or allows that function will be indicated inside the blob.

A blob has the following elements:

Function: It describes the function of the overall system that the blob is representing.

Actor: It is the device, equipment or system that performs the function. For example: heat exchanger, reactor or vessel.

Condition: It is a boolean variable of the blob which is necessary for the function to be carried out.

Using different colors can differentiate between different types of blobs, however, we also to point out the hierarchy of these blobs. To that end, we use the same color for the same kind of blobs but with different saturation. The ancestor blob is painted using a less saturated color than its descendant, which, therefore, is colored using a more saturated color. In the following table the colors of the different kinds of blobs are presented using a HSB (Hue, Saturation and Brightness) color model. The value H, ted in the table, are percentages of each of its component [9].

Table 2. Color references

Type	Color	H S B	R G B	Sample
Control	Orange	40 25 100	255 234 191	🟧
Process	Green	78 30 100	234 255 131	🟩
Blend	Blue	199 13 100	222 242 255	🟦

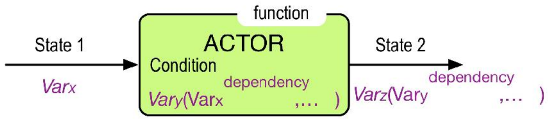


Fig. 1 Basic blob

Edges: Edges represent flows of mass, energy or information, which are responsible of all of the interactions in a process system. These edges are depicted differently, as shown in the Figure. 2 [12].

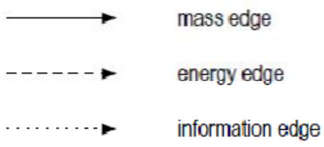


Fig. 2 Types of edges

The main properties of blobs and edges are:

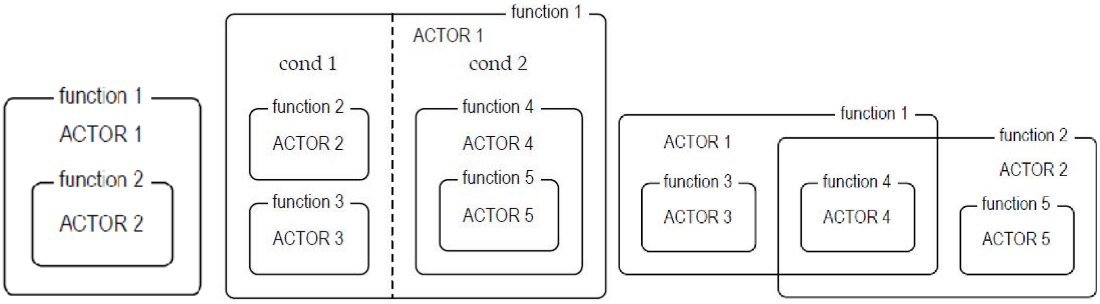
Blob connection. An edge always links two blobs. Under certain conditions, one of the blobs is not represented (elliptic blob), but it exists.

Blob inclusion. Blobs can be included inside 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) (Fig.3-a-).

Partitioning blobs. A blob can be partitioned into orthogonal components, establishing an OR condition between the partitions (Fig.3-b-).

Blob intersection. The interpretation of the intersection of blobs is that actors can share devices or subfunctions (Fig.3-c-).

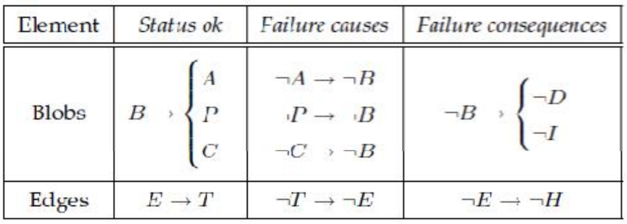
The main objective of D-higraphs is not only the representation of knowledge about process systems. There are a series of causation rules implemented that provides relating two events which allows us to track the evolution and propagation of failures across the system. These rules, combined with sensor data of the plant, enable the possibility of performing FDI analysis using D-higraph models. In a certain way, we need to simulate qualitatively the system in order to propagate these deviations. So the D-higraph is not only a tool of modeling but it has two other objectives, the causal reasoning with some rules as depicted in the table 2 and the qualitative simulation, The main objective of simulation is to make predictions about the behavior of the system as shown in the figure 4 [13].



-a- -b- -c-

Fig. 3 Properties of blobs. a- inclusion, b- partitioning, c- intersection

Table 3 Summary of causal relations.



Element	*Status ok*	*Failure causes*	*Failure consequences*
Blobs	$B \rightarrow \begin{cases} A \\ P \\ C \end{cases}$	$\neg A \rightarrow \neg B$ $\neg P \rightarrow \neg B$ $\neg C \rightarrow \neg B$	$\neg B \rightarrow \begin{cases} \neg D \\ \neg I \end{cases}$
Edges	$E \rightarrow T$	$\neg T \rightarrow \neg E$	$\neg E \rightarrow \neg H$

SADT method

SADT, which was designed by Ross in the 1970s, was originally destined for software engineering but rapidly other areas of application were found, such as aeronautic, production management, etc.

SADT is a standard tool used in designing computer integrated manufacturing systems, including flexible manufacturing systems [14].

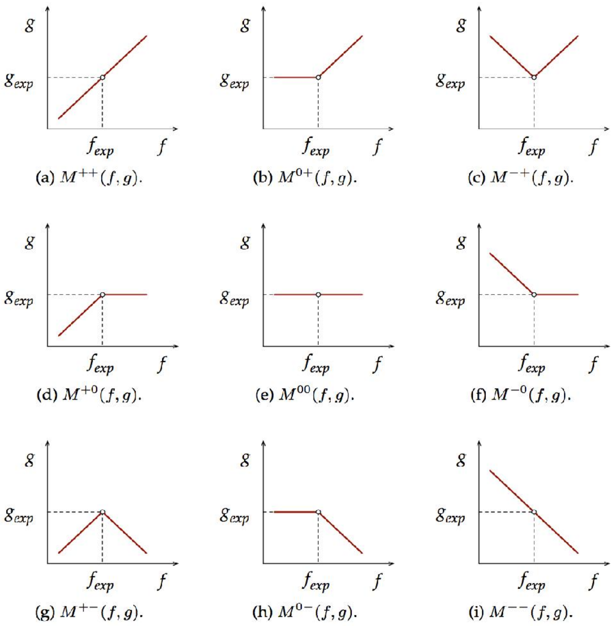


Fig. 4 The M-constraint family

4. CASE STUDY

Our case study is the HDPE reactor that install on the CP2K plant. That is an Operational Unit of the national Company SONATRACH. It is located in the industrial area "Oil-rig SKIKDA." The production of high-density polyethylene from ethylene as the main raw material is based on the PHILLIPS PETROLEUM COMPANY process (particles process). It consists essentially at the catalytic polymerization of the ethylene in a closed continuous tubular reactor, in liquid phase (forming a suspension in iso-butane).The highly exothermic chemical reaction (800 Kcal/Kg approximate.) occurs at a temperature in the range [85-110] °C and under a pressure of 42- 44 kg/cm² [14].

Process description

The HDPE reactor (Fig.5) is piping with internal diameter of 560 mm in the form of loop, composed of four vertical sections, linked by horizontal sections. The vertical sections have Jacket insulated for refrigeration. Those, made of carbon steel with external diameter 760 mm, are designed to the pressure and the temperature of 15 kg/cm²g and 142ºC respectively. The reactor can be decomposed into the four following parts:

The reactor enclosure

The reactor pump

Refrigeration system

Decantation legs.

The reactor feed streams (ethylene, iso-butane, hydrogen and 1-hexane, in the case of the production of copolymers) require a high degree of purity, for this; they are in advance treated to remove any catalyst poison (basically acetylene, oxygen, and water) until not harmful residual contents. This is accomplished in suitable catalytic caterers, in the case of ethylene, degassing columns, iso-butane and hexene-1, and specific dryers for all currents. The reactor is fed with the raw materials processed at the treatment area. Recycled iso-butane, hydrogen, hexene-1 and ethylene arrive at the reactor through the main supply line to the reactor. Hexane and recycled iso-butane are mixed in the static mixer iso-butane / hexane. Hydrogen is mixed with the ethylene and it is added to the stream of recycled iso-butane / hexane at the mixer output. The feed to reactor at different flows is adjusted based on certain variables. The iso-butane-ethylene-polyethylene mixture flows into the reactor through the reactor pump [15].

D-higraph of the HDPE reactor

According to the decomposition above described and the structure of the HDPE reactor, the D-higraph of the system can be developed. This D-higraph presents not only the functionality of the system with its goals and subgoals, but also the relation existing between these functions/goals and the devices that perform/achieve them. 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 such as vessel, jacket, and reactor pump and so on but it also includes the control system elements such as control loops with their components.

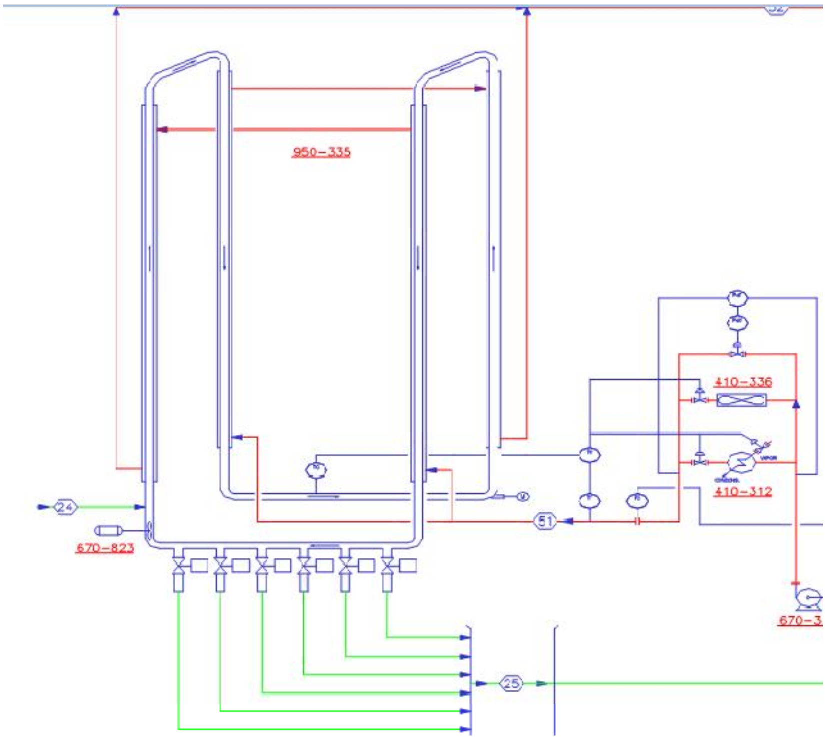


Fig. 5 The HDPE Reactor

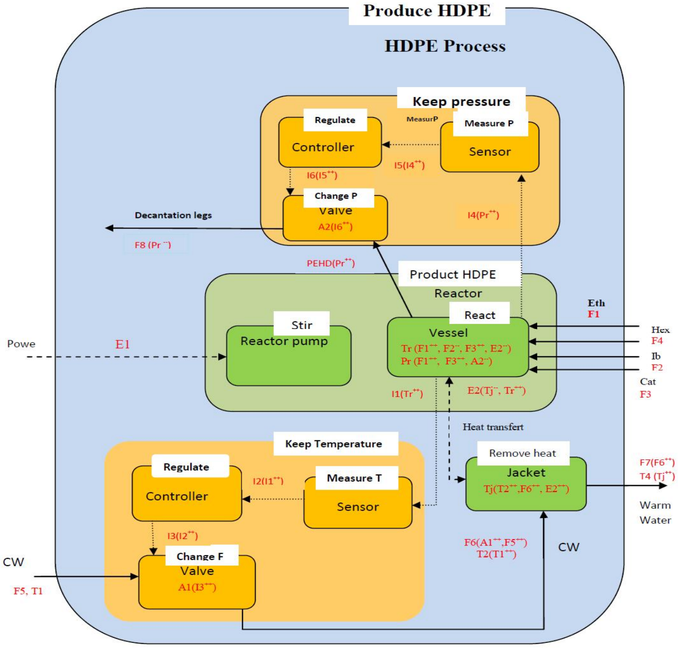


Fig. 6 D-higraph of the HDPE Reactor

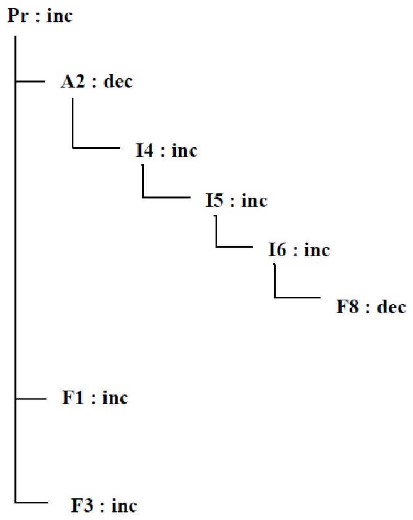


Fig. 7 Causal tree of deviation Pr: inc

Deviation 1: High pressure

This deviation corresponds with the variable “Reactor pressure Pr” and the HAZOP guide-word “MORE OF”. According to the methodology presented and the D-higraph in (Fig. 6), the causal tree obtained is shown in the (Fig. 7) and the consequences graph is shown in the (Fig.8). This tree can be directly translated to the variables of the process: The fact that the pressure in the reactor is higher than its expected value (Pr: inc) can be motivated by a higher flow in the flow from the ethylene compressor (F1: inc) or by a higher flow in the flow from the catalysis (F3: inc) or by the opening of the valve less than it should be (A2: dec). Caused by Low control signal to the valve (I6: dec). Caused by a low measured pressure (I5: dec), caused by low pressure seen in the vissel (I4: dec).

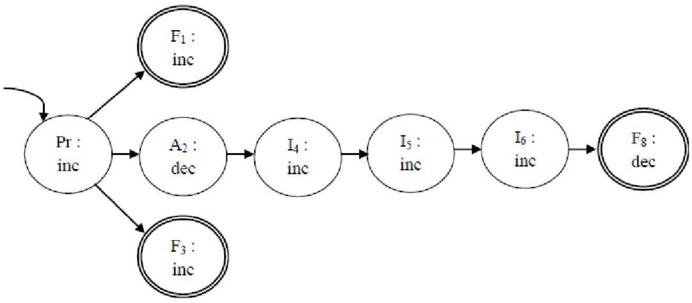


Fig. 8 Consequences graph for Pr = inc

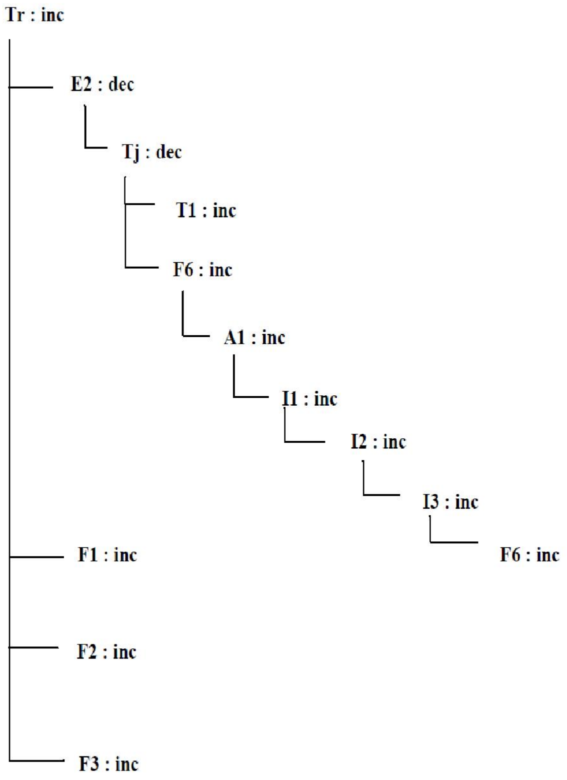


Fig. 9 Causal tree of deviation Tr: inc

Deviation 2: High temperature

This deviation consists in the variable “Reactor temperature Tr” and the HAZOP guide word “MORE OF”. According to the methodology presented and the Dhigraph in (Fig. 6), the causal tree obtained is shown in the (Fig. 8) and the consequences graph is shown in the (Fig.10). This tree can be directly translated to the variables of the process: The fact that the temperature in the reactor is higher than its expected value (Tr: inc) can be motivated by a higher flow in the flow from the ethylene compressor (F1: inc) or by a lower flow in the flow from the iso-butane pump (F2: dec) or by a low energy transfer (E2: dec), caused by the lowe temperature in the jacket (Tj: dec), caused by the height flow temperature (T3: inc). Caused by the height flow of the CW (F5: inc). Caused by the opening of the valve more than it should be (A1: inc). Due to height control signal to the valve (I3: inc). Caused by a hieght measured temperature in the reactor (I2: inc), caused by hieght temperature seen in the reactor (I1: inc). Caused by height flow of CW.

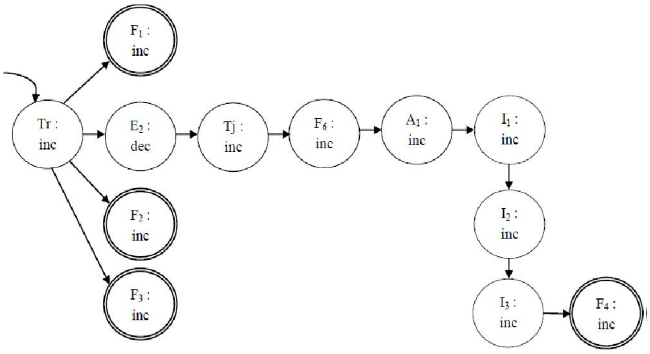


Fig. 10 Consequences graph for Tr = inc

Comparison with SADT method

We use SADT method, to decompose the system and identify the principal elementary subsystems to study them. The actigramme A0 (figure 8) presents the principal functionality “Produce the HDPE”. A decomposition of this functionality shows in the actigramme A1. The actigramme A1 has three sub-functionality (A1-1, A1-2 and A1-3) “inject into the reactor”, “maintain the reaction conditions” and “recover the products of reaction” (figure 9) [16].

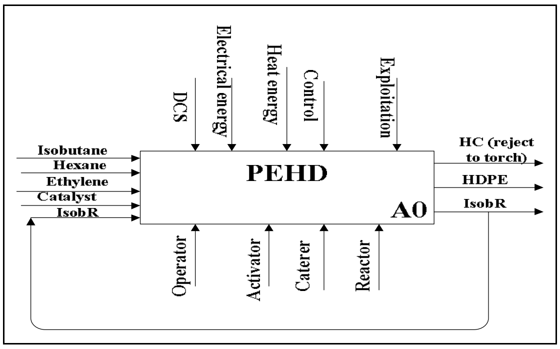


Fig.11 Decomposition of the system by SADT (Level 1)

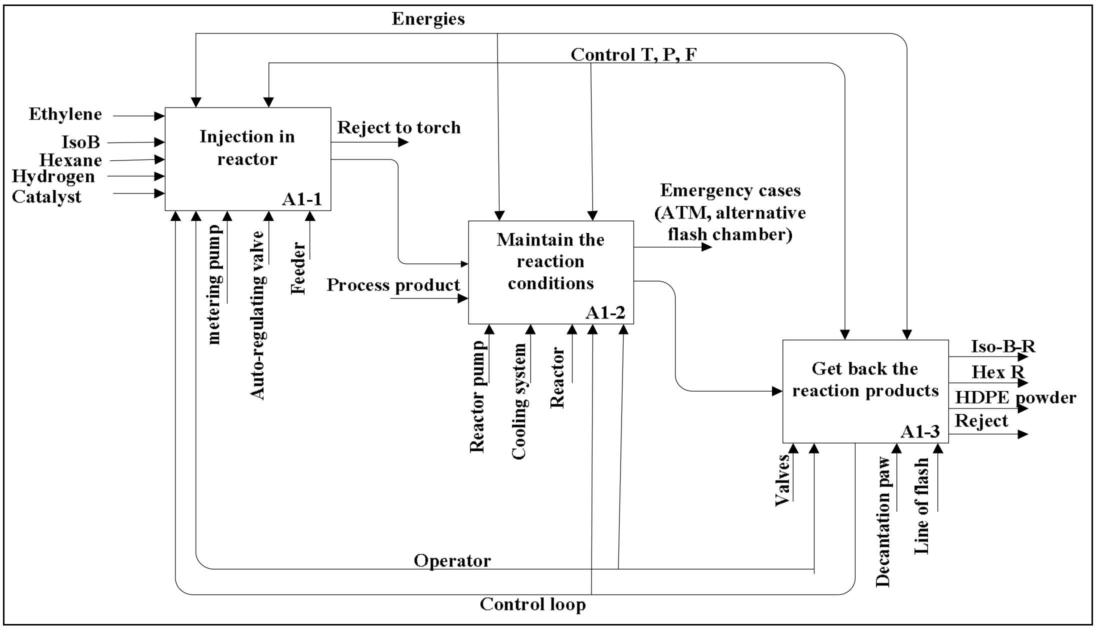


Fig.12 Decomposition of system by SADT (Actigramme A 1).

We notice that the functionality of system is quite clear with its various functionalities on this level of decomposition.

The SADT method uses just to describe how is the system work, by the decomposing it into the sub-systems. It can’t provide any information about potential failures or hazards, for that it needs to be completed with a dysfunctional analysis method as FMEA, HAZOP, ETA, FTA..etc. However D-higraph integrates functional and structural information, it uses a single model for the whole study and it is used to determine potential faults, consequences, etc, in terms of causation.

Comparison with traditional HAZOPstudy

We use HAZOP study, to make a dysfunctional analysis of the HDPE reactor to identify all deviations, their causes and their consequences. The most critical scenarios obtained by the application of traditional HAZOP are summarized in the following table [17].

The result of a traditional HAZOP of the HDPE reactor when compared to the results of the D-higraph assistant HAZOP shows that similar causes of the deviations are found. Traditional HAZOP can’t provide any information about functional or structural of the system, for that it needs to be completed with a functional analysis method as FAST, SADT,..etc.

Table 4 Critical scenarios obtained by hazop study.

N^0	Scenarios	deviations	Causes	Criticality
02	Explosion + Fire	high temperature	-High flow of Hexane -Stopping of the cooling pump	C1
		high pressure	-High flow of iso-butane -High flow of ethylene - Filling up of PTO valve -High flow of hexane -High flow of ethylen	

However D-higraph HAZOP assistant integrates functional and structural information, it uses a single model for the whole study. Every item in a D-higraph HAZOP assistant has a direct relation with an item of the process being studied. It is used to determine potential faults, consequences, etc, in terms of causation.

During the D-higraphs HAZOP assistant, deviations are propagated in an automatic and systematic way, i.e., each node is fully explored and no branches are left unexplored. The causes and consequences trees can be extended even beyond the node itself. With all of these features, the quality of the analysis is improved while reducing the time involved, if compared with traditional HAZOP studies.

5. CONCLUSION

In this paper, we modeled the HDPE reactor by D-higraph HAZOP assistant method. The model presents the structural information and functional information, one or both of the views can be displayed and focused on. After that we can extract the causal trees to find the root causes and consequences graphs. Then we have compared the modeling by D-higraph HAZOP assistant methodology with traditional HAZOP. We notice that the HAZOP study cannot provide any information about the function of the system or its structure, for that it needs to complete study by a functional analysis method, while D-higraph HAZOP assistant integrates functional and structural information, it uses a single model for the whole study and it is used to determine potential faults, consequences, etc, and save time, effort and money.

References

[1] J. Dunjó, V. Fthenakis. Juan A. Vílchez and J. Arnaldos. “Hazard and operability (HAZOP) analysis. A literature review“. Journal of Hazardous Materials. pp19. 2010..

[2] L. FROQUET. Contribution à l'analyse des risques : Proposition d'une méthode par scénarios et capitalisation de la connaissance. Thèse de doctorat de laboratoire d’automatique de Grenoble dans le cadre de l’école doctoral électronique, électrotechnique, automatique, télécommunication, signal, France .p 125 .2005

[3] C. Jeerawongsuntorn, N. Sainyamsatit & T. Srinophakun. Integration of safety instrumented system with automated HAZOP analysis: An application for continuous biodiesel production, Loss Prevention in the Process Industries, pp 412-419. 2011.

[4] Zhao, C., Bhushan, M., & Venkatasubramanian, V. PHASuite: An automated HAZOP analysis tool for chemical processes. Part I. Knowledge engineering framework. Process Safety and Environmental Protection, 83(6), 509–532. 2005.

[5] Rossing, N. L., Lind, M., Jensen, N., & Jørgensen, S. B. A functional HAZOP methodology. Computers & Chemical Engineering, 34(2), 244–253. 2010.

[6] El. Mechhoud, M. Rouaïnia. “AUTOMATED DEPENDABILITY ANALYSIS OF A HDPE REACTOR”. 48 th ICCST-IEEE-. Rome- Italie.pp5. 13-16 October 2014

[7] B. Debray, S.Chaumette, S. Descouriere, V. Trommeter. Méthode d’analyse des risques générés par une installation industrielle Ω-7. Rapport d’étude, N° 46055-CL47569, INERIS-DRA. p 140. 2006.

[8] P.K. Marhavilas, D. Koulouriotis, V. Gemeni Risk analysis and assessment methodologies in the work sites: On a review, classification and comparative study of the scientific literature of the period 2000-2009. Journal of Loss Prevention in the Process Industries. pp 47. 2011.

[9] J. Luis de la Mata, “Integral management of abnormal situations in complex process plants”, Ph. D thesis, UPM, ETSII. pp 322. 2013.

[10] Manuel Rodríguez, José Luis de la Mata. Automating HAZOP studies using D-higraphs. Computers and Chemical Engineering 45. pp 102– 113. 2012.

[11] J. Luis de la Mata, M. Rodriguez, “Abnormal Situation Diagnosis Using D-higraphs”, ESCAPE20, Elsevier B.V. 2010.

[12] M. Rodriguez, I. Diaz, “A new functional systems theory based methodology for process hazards analysis”, ESCAPE 24, 2014.

[13] M. Rodriguez, J. Luis. De la Mata, I. Diaz, « Fault- Tolerant Self Reconfigurable Control System », ESCAPE 23, 2013.

[14] Operation manual PHILIPS (CP2K)El Arkam Mechhoud & Mounira Rouainia. Dependability analysis of HDPE reactor. 7 th International Symosiom on Hydrocarbon and Chemistry Boumerdes- Algeria. pp 9.2014.

[15] El Arkam Mechhoud & Mounira Rouainia. Application de la méthode HAZOP su le réacteur PEHD. 9ème Congrés Francophon de Gènie des Procédés , Agadir- Marroc. pp 9. 2014.

[16] El. Mechhoud, M. Rouaïnia, M. Rodriguez. Functional Modeling of a HDPE Reactor using Dhigraphs for process hazard analysis. 8th International Conference on Modelling, Identification and Control (ICMIC-2016) Algiers, Algeria- November 15-17, 2016.

[17] El-A. Mechhoud, M. Rouainia. “DEPENDABILITY ANALYSIS OF A HDPE REACTOR”. ishc7’. Boumerdes, Algeria. pp 82014.