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Emergency Response Plan Modeling Using IDEF0 and BPMN Approaches

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ABSTRACT

Emergency response plans play a key role in limiting the consequences of major accidents and consequently preventing them from causing domino effects. It is therefore crucial to efficiently design and implement emergency response plans according to the expected accidents. Within this framework, this paper is aiming to present a structured approach in order to model and evaluate the performance of such plans, based on IDEF0 and BPMN (Business Process Modeling Notation) methods. In fact, the IDEF0 allow a detailed functional and structural description of the emergency response plan, whereas the BPMN is used to clarify the relations between its different components and to simulate it. The simulation results give valuable information regarding the execution of the emergency response process, especially the required time to reach a safe situation. The proposed approach was illustrated on a special emergency plan called “Internal Intervention Plan: IIP” related to a gasoline storage leakage that may lead to a major accident scenario (fire) within an LNG facility.

1. INTRODUCTION

Major accidents in gas and oil industry, such as fire, explosion, release of hazardous materials, etc., cause huge losses for potential targets (people, property and the environment). This reality is attributable to the large quantities and dangerous properties of the materials used and to the severe operating conditions (high temperature, pressure, etc.). In addition to the inherent safety and supplementary safety barriers intended to prevent or control major accidents, effective emergency response plans play a key role in preventing a major accident from causing a secondary accident and thus potentially forming a domino effect. In order to ensure the rapid, orderly and effective implementation of emergency response procedures, emergency response plans are usually developed in advance in process plants. These plans arrange in prior the emergency organization’s structure, personnel, technology, equipments, materials, procedures, orders and coordination.

To help establishing such plans, many guidelines have been published to assist the work of emergency responders in handling emergency situations in the chemical industry, such as the Centre for Chemical Process Safety (CCPS) [1], the U.S Federal Emergency Management Agency (FEMA) [2], the Oil and Chemical Industries Safety Studies Group in France (GESIP) [3], UK Health and Safety Executive (HSG191) [4], the European Union ‘Seveso-III’ directive (Council Directive) [5], and Incident management system for oil and gas industry [6].

The evaluation of emergency response actions has become an urgent requirement for improving emergency preparedness, since emergency actions in response to an accident can significantly affect its evolution. Different patterns of an accident evolution may lead to different consequences. As a result, the efficacy of the emergency response actions and their impact on both the evolution of the accident and the likelihood of the ensuing consequences should be effectively taken into account in the risk analysis [7].

Some studies on the evaluation of emergency response plans have been carried out [8-13]. Most of these researches aimed to evaluate the emergency plans from robustness and integrity perspectives [7]. However, the relevant studies in the field of emergency response actions are still relatively limited. For example, regarding risk assessment, Antonioni et al. [14] applied recently developed equipment damage probability models to identify end scenarios and assess the likelihood of escalation. Khakzad et al. [15] introduced a Bayesian network-based methodology to model risk patterns with a domino effect in order to estimate the probability of its impact at different levels. The probabilities of events can be updated in light of new information. Based on probabilistic models and physical equations, Kadri et al. [16] presented a methodology for the quantitative assessment of the hazards and domino effects of fire and explosion in storage areas. A human exposure model to the effects of excess pressure and heat radiation was developed to estimate individual and societal risks. In addition, Khakzad et al. [15] introduced a dynamic outcome analysis approach to evaluating risks and managing their impacts and demonstrated the application of Bayesian networks and conflict analysis to allocate risk-based chemical inventories to minimize consequences and reduce the potential for escalation.

For the escalation thresholds, Cozzani and Salzano [17] studied the definition and assessment of overpressure threshold values for the damage to equipment caused by blast waves which are originated by primary accidental scenarios, and they proposed threshold values for different categories of process equipment, taking into account either damage levels or release intensities following the loss of containment. Cozzani et al. [18] further studied the revision and the improvement of criteria for escalation credibility, based on the modeling of explosion, fire or release of toxic gas damage to process equipment due to different escalation vectors, and proposed revised threshold values. Landucci et al. [19] developed an approach for the quantitative assessment of the risk caused by escalation scenarios triggered by major accidents like explosion, fire or release of toxic gas.

Major accident, toxic gas clouds, overpressure waves and heat radiation effects do not delay to claim their toll. Therefore, emergency planning as mitigation measure plays a key role in reducing the risk of accidents by avoiding fatalities and injuries, protecting the environment and accelerating the resumption of normal operations [20].

The occurrence of major accidents in the oil field around the world is a proof that the risk is omnipresent. Hence, the control of major accidents requires a global approach, allowing, on the basis of the analysis of the feedback, to enrich the reflection, already started on how to adopt major risks in the area of constituency and the most effective means to implement both in the prevention stage and in emergency management and contingency planning [21].

Internal Intervention Plan (IIP) is a specific emergency response plan and it is regarded as a major safety barrier in the emergency response stage. It is a grouping of all measures to be implemented in the event of a major industrialaccident in order to prevent or reduce the associated adverse effects in the shortest possible time [21].

There are a large body of published studies in terms of assessments of internal intervention plan and emergency response performance for chemical accidents. Some studies have used quantitative analytical methods. For example, Karagiannis [22] presented a function-interaction-structure (FIS) modelling approach to measure the robustness of an internal or external industrial emergency plan.

Thanh et al. [23] simulated and analyzed the tsunami emergency plans from a model perspective. An earthquake and tsunami resolution plan was represented as a Business Process Model and Notation (BPMN) approach.

In this paper, we carried out a structural/ functional modeling of the Internal Intervention Plan (IIP) adopted in the oil and gas industries in Algeria. The IIP is triggered in the event of a major accident detected such as fire, explosion and toxic release. The rest of this paper is organized as follows. Section 2 and 3 details the different aspects of an IIP in the context of Algerian oil and gas industry. section4 describes the proposed methodology based on a combination of IDEF0 and BPMN methods. An illustration of that approach is given in section 5 the structural modeling of the IIP is performed using the IDEF0 technique, whereas the functional modeling and simulation of the IIP is carried out thanks to the BPMN approach. A wrap up of this study is given in section 6.

2. DESCRIPTION OF THE INTERNAL INTERVENTION PLAN (IIP)

The IIP is established to define the organization of relief and disaster response within a given industrial facility. It aims to protect the personnel, the public and the immediate environment and describes the measures to be taken to restore the safety of the facility and to prevent the disaster from becoming more widespread [24]. The IIP is based on the risk analysis. It defines the conditions for managing the accident and its consequences. It describes according to the major accident scenarios, the organization of the alert, the rescue and the response. More specifically, for each scenario, the IIP defines the strategy of the intervention, the first interventions, the course of the attack and the means required for each phase of the intervention. Risks of escalation of the disaster are identified, the action and precautions to be taken are reported.

2.1 Missions considered in the IIP

The IIP defines a 3-level emergency organization (the response teams as shown in Figure 1, an Operational Command Post, an Internal Operations Management Post) set up internally to establish the interface with the other plans (PAM, ORSEC, Crisis, etc.) and also the various third parties involved in the accident. It specifies the structure of this organization, the exact role of each stakeholder and the hierarchical links between the different entities involved [24].

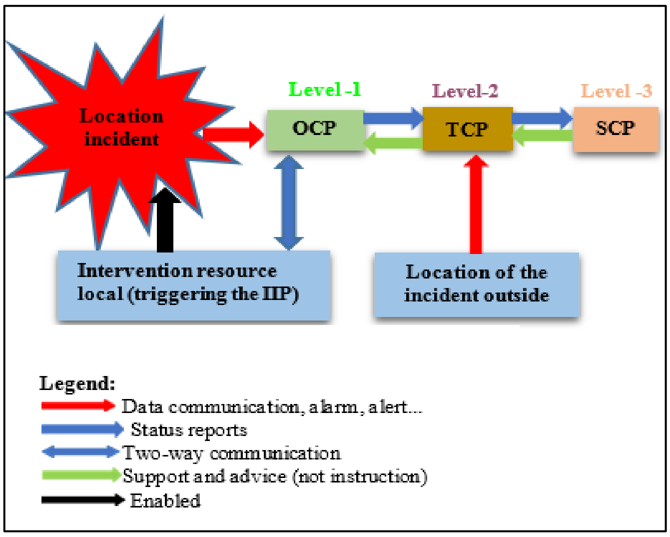

Figure 1. Communications structure

2.2 The value of an IIP

This plan is a well-defined management of major emergencies. In addition to providing guidance during an emergency, the IIP has other benefits. The development of this plan can identify and eliminate undetected risks that could aggravate an emergency situation. The planning process identifies gaps, including a lack of resources (equipment, trained personnel, supplies) that can be addressed before a situation occurs. In addition, an IIP promotes security awareness and emphasizes the organization’s commitment to the safety of its employees.

2.3 Activating the IIP

Alerting is the most important function as it triggers the IIP. [25] The latter defines the alert chain that illustrates the logic used on the site regarding the organization of communications and the mobilization of the actors involved. This chain begins with the detection of an incident by automatic means or by a witness. After the incident detection, the alert is passed on to all IIP actors who are thus mobilized. Finally, when the situation is under control, the end of the incident is reported by the appropriate level of management.

3. PERFORMANCE ASSESSMENT APPROACHES OF IIP

There are three approaches to evaluating the performance of IIP, namely [25]:

3.1 Assessment by feedback

Feedback is important to improve the performance of emergency response in industrial operations. In order to assess the overall effectiveness of the different measures used in the IIP, simulation exercises are essential tools. Indeed, the simulated implementation of the plan will be an opportunity for the participants to put into practice the theoretical learning, to familiarize themselves with their roles and responsibilities in an emergency situation and to validate the different procedures established in the IIP.

Improvement of IIP through feedback is generally based on reports following simulation exercises and incidents requiring activation of the IIP. Although actual accidents are the only true test of the plan, simulation exercises can also assess some or all of the IIP [25]. At the end of the simulation, all the actions carried out are analyzed to identify the causes of any non-conformities. The reports shall contain a brief narrative of the operation, accompanied by a presentation on the elements of the action which have worked well or poorly and proposals for improvement.

Feedback process identifies failures that have already occurred but does not allow for a comprehensive IIP analysis [25]. Several authors have already highlighted the need for a systemic analysis of these plans.

3.2 Audit assessment

The audit approach to assessing IIP is to directly assess the performance of the plan using questions and factors identified by a large number of experts [25].

Performance is assessed by questions focused on the quality of the plan, the consideration of all indicators defined in the methodology, and the plan's ability to meet regulatory requirements. Scores are assigned to the answers to these questions, and a final score is produced. Despite its pragmatic and relevant nature, this method lacks of structure. In fact, the identification of factors to be assessed is based on expertise and does not take into account the structure of the IIP. Moreover, the aggregation of scores is based on a sum of the points obtained by the different questions and does not take into account the relative importance of the different aspects of the plan [24].

3.3 Evaluation of IIP using the FIS model

The National School of Mines of Saint-Etienne (France) [24]. has developed a method for the analysis of the robustness of IIP using the FIS method. This research used the computer tool (XRisk) developed for structural-functional modeling and risk analysis of complex systems. The model was used to structure the analysis and to identify potential failures during crisis management.

Each type of resource is characterized by a set of attributes (including fault trees) that allow the probability of resource failure to be calculated. The probability of failure of the model functions is calculated from the associated resource failure probabilities across the fault tree of each function. The severity of each function is estimated according to the maximum consequences of its failure on the system and its environment. The combination of the probability and the severity of failure of each function results in its criticality. The robustness of the IIP is expressed in terms of its failure criticality, which is obtained from the aggregation of the criticalities of its functions.

However, the aggregation of function criticalities does not take into account the relative importance of the different plan functions and the performance is assessed qualitatively, hence the importance of evaluating the IIP quantitatively.

4. PROPOSED APROACH

The modeling of a system provides a complete and coherent model for the system functions (activities, actions, processes and operations) required by a public information chain in the event of an emergency, as well as the relationships and data supporting the integration of this system [26]. In this paper we propose a methodology based on the combined use of the IDEF0 and BPMN approaches.

4.1 The IDEF0 approach

IDEF0 is a modeling language with graphical and textual features that provides a standard template for the decisions, functions and activities of an enterprise, process or system. It is based on the Analytical and Structured Design Technique developed in 1972 by Douglas (T. Ross) and (SofTech), Inc. (Marca and McGowan, 1988). IDEF0 is now an IEEE standard (KBSI, 1998). In each diagram, the activities, processes and transformations are represented by boxes describing their function. Function-related data and objects are represented by arrows. As shown in Figure 2, the role of an arrow is determined by its relationship to a function area:

- The inputs transformed or consumed by the function to produce outputs are represented by arrows entering in the left part of the box;
- Controls specifying the conditions required for the function to produce correct outputs are represented by arrows entering the area at the top;
- outputs corresponding to the data or objects generated by the function are represented by arrows leaving a frame on the right;
- The mechanisms that are the means required to perform a function (human or material resources) are represented by arrows attached to the bottom of the box.

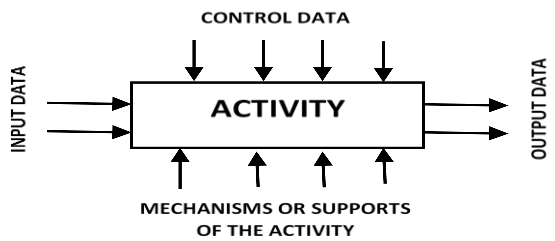

Figure 2. Actigram of the IDEF0 model

IDEF0 models are created by a bottom-up analysis process, but they have a top-down representation and interpretation. A model includes a series of hierarchical diagrams and associated materials. A higher-level context diagram, called

Diagram A-0, defines the context of the model and defines its purpose and perspective. Diagram A-0 can be broken down into sub-functions represented in a child diagram, and each sub-function can again be broken down into low-level child diagrams.

4.2 BPMN approach

The BPMN “Business Process Modeling Notation” language is a standard for the modeling of a company’s business processes, allowing defining a common graphical notation for all modeling tools.

BPMN is chosen in this study because it is a powerful language of modeling that describes the flow of the process by using the proper events, activities and gateways [26].

The main objective of BPMN is to provide a common framework for describing a process in a way that is understandable to all the actors of a company, from business analysts who create the initial drafts of the procedures, up to the developers responsible for setting up the technology thatwill execute these procedures [27].

BPMN decouples business information from technical information and provides correspondence to runtime languages.

4.2.1 BPMN graphical elements

A BPMN diagram consists of a set of graphical elements that allow modelling activities, flows, relationships, data and their interactions. It is structured around four categories of elements as shown in Figure 3.

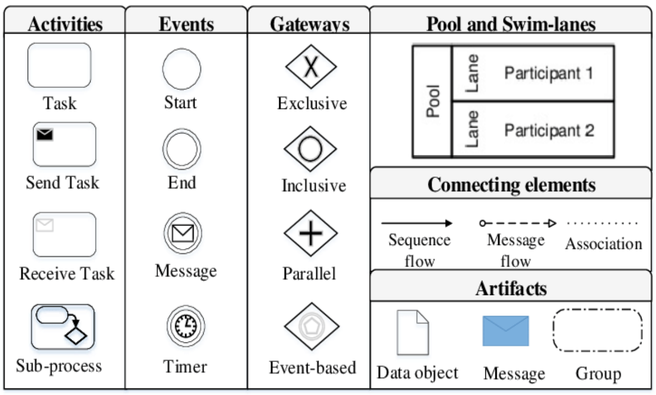

Figure 3. Basic elements of a BPMN

•Flow Objects: these are the main graphical elements that define the behaviour of a business process. There are three types of flow objects:

-Activities: activities that correspond to an action that can be performed by a human or machine. They have a beginning and an end and can only begin if the previous activities are completed. An activity can be atomic or composite.

-Events: events that correspond to an action that occurs during the process. They usually have a cause and a consequence. This makes it possible to change the course of a process when a particular event occurs during the execution of the process. There are three categories of events: Start, Intermediate and Stop.

-Gate-ways: which correspond to a connection in the process and allows representing an action in the progress of the latter.

•Connecting Objects: these are the graphical elements that allow to connect the flow objects to each other to represent the flow of the process. There are three kinds of object connector: the “Sequence flow” which indicates the execution order of the actions, the “Message flow” which correspond to a link between two separate processes and finally, the “Association” which allow to link data or documents to process objects.

•Swimlanes: these are the graphical elements used to structure and group the different elements that make up the BPMN diagram. These are the partitions (Pools) and the sub-partitions (Lanes) [28].

•Artifacts: are used to provide additional information about the process. There are three types of artifacts: “Data object” that show how the data are linked to a task (via an association), “Groups” which allow to group together tasks of the same category in order to better locate them visually and finally, “Annotations” which allow to add comments to facilitate the reading of the BPMN diagram [29].

5. CASE STUDY

The proposed approach based on IDEF0 and BPMN is illustrated on an IIP related to a gasoline storage tank fire. This major accident scenario was identified within an Algerian LNG facility.

5.1 Gazoline storage sphere 76-MD-03

The gasoline produced by the deisopentanizer is stored in the 76-MD03 sphere as shown in Figures 4 and 5, with a capacity of 3000 m³, before sending it to the refinery [30]. Normal operating pressure is 0.51bar g. The maximum operating temperature is +62°C and the minimum temperature is +1°C. Physical characteristics of gasoline are given in Table 1.

5.2 Scenario description

The internal intervention plan is executed after the detection of a leak in the gasoline storage that has led to a major accident scenario (fire) inside the LNG installation [30], through the successive stages below the plan modeling through the IDEF0 approach and each step is developed and detailed by BPMN:

Table 1. Physical characteristics of pentane (gasoline)

product	**liquid**		**flash point C°**	**boiling point C°**	**vapor pressure at 38C° (kg/cm²)**	**self-ignition point C°**	**flammability limit %**	
	density at 15°c	vapor					lower	upper
Pentane C5+	0,63	2,49	-40	36	1,1	309	1,5	7,6

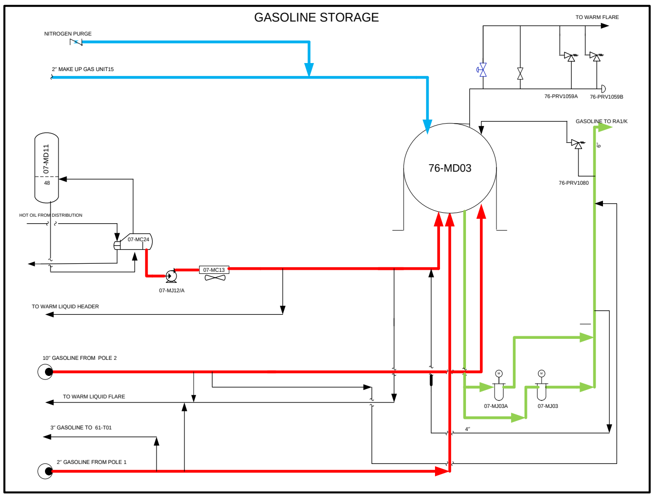

Figure 4. Gasoline storage sphere 76-MD-03 [30]

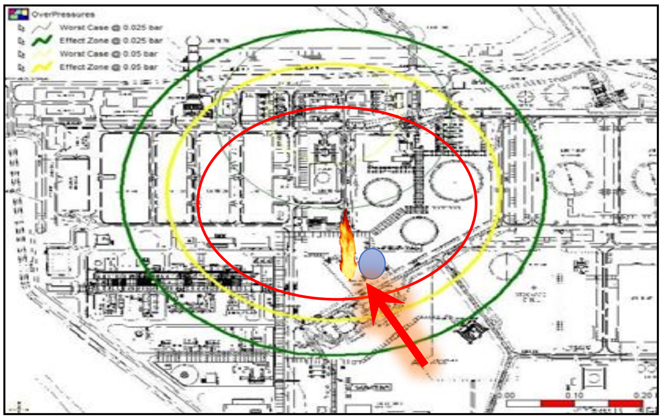

Figure 5. Location of flash fire/gasoline storage tank

a. Declaration of an alert/alarm:

- Detection of the presence of gas around the Gazoline sphere displayed on CCR by gas detector (alarm 20% LEL).
- Confirmation of the leak by video surveillance system CCTV camera.

b. Gathering:

- Gather the people concerned;
- Quickly inform the tactical command post (TCP) (there is a possibility that neighboring sites may be affected);
- Establish specific gathering requirements.

c. Product insulation:

- To be done as soon as the alert is declared (Stop all entries and exits of the equipment concerned).

d. Removal of the product and protection of the equipment:

- This step ensures that the leak is attenuated and that the local accumulations have not dissipated;
- Cool the surroundings of structures, tanks, process areas, etc;
- Attempts to moisten the surface actually touched pushes the water away before it can take effect;
- That said, a tank affected by a trocheal flame on one of its surfaces can be protected by cooling the surroundings of the unaffected parts;
- Deploying resources from the upwind side provides closer access and less exposure to the effects of heat or smoke.

e. Evacuation of the site:

- Keep people inside safe from escape: at height, with doors and doors and windows closed, and ventilation systems turned off.

f. Evacuation off site:

- If homes and businesses are potentially affected by dispersed gas/fluid (if toxic), close doors/windows and stay indoors, on upper floors if possible.

g. Environmental protection:

- Do not act until the event is over, but make the heavy equipment response team look like.

h. Protection of property:

- Do not act until the event is over.

i. Withdraw (end of alert): to do that:

- the leak is totally quiet (recognizable by the noise reduction of the leak);
- the fire is out and surrounding hot surfaces have cooled completely and residue has been cleaned and removed;
- Back to normal;
- Declared all clear;
- Develop a detailed report to the TCP and to update the IIP (feedback).

5.3 Modeling of the IIP using the IDEF0 approach

First, we modeled the internal intervention plan using the IDEF0 approach, which allowed a functional analysis of the IIP that is top-down, modular, hierarchical and structured. From the modeling of the IIP events, i.e., activities carried out by men and machines, we have shown the relationships that exist between them and the way they fit into a hierarchical structure when there is a major accident (alert) and the IIP is triggered, including:

- **Level 01 «A0» Global vision of the IIP**: it shows a global vision of the IIP and presents just the inputs, the outputs, as shown in Figure 6, the used resources and the possible constraints in a general way when the major accident is detected.
- **Level 02 «A1»: Communication of the IIP with the other safety barriers**: this second established model depicts the global management process in the major incident, as shown in Figure 6. It shows how the three levels of safety barriers communicate with each other and how the first safety barrier (Level 1/IIP) communicates with the other levels during the exacerbation of their interference in the response.
- **Level 03 «A2»: Model to understand**: represents a hierarchical structural modeling of the IIP triggering when an alert/alarm occurs indicating an incident detection. As shown in Figure 6
- **Level 04 «A3»: Top-down modeling of the IIP**: after obtaining the general description of the IIP (A0 and A2) and the relation with the other levels (A1), A3 diagram gives a functional modeling of the IIP (decomposition of A0), which clearly shows the relationships between all the elements, as shown in Figure 7:
    - **Box A31:** represents the fire detection by means of an alert/alarm and the arrows represent the resources used, the constraints and the outputs for each stage of the IIP.
    - **Box A32:** triggered when the previous step gives a command which takes into account an input from A32

and this if the incident situation is not under control.

- **Box A33:** triggered when the previous step gives a command which takes into account an input from A33 and this if the incident situation is not under control.
- **Box A34:** This is the last stage of the IIP, triggered when the previous stage gives a command which takes into account the entry of A34 and this if the incident situation is not under control.

5.4 Modeling of the IIP using the IDEF0 approach

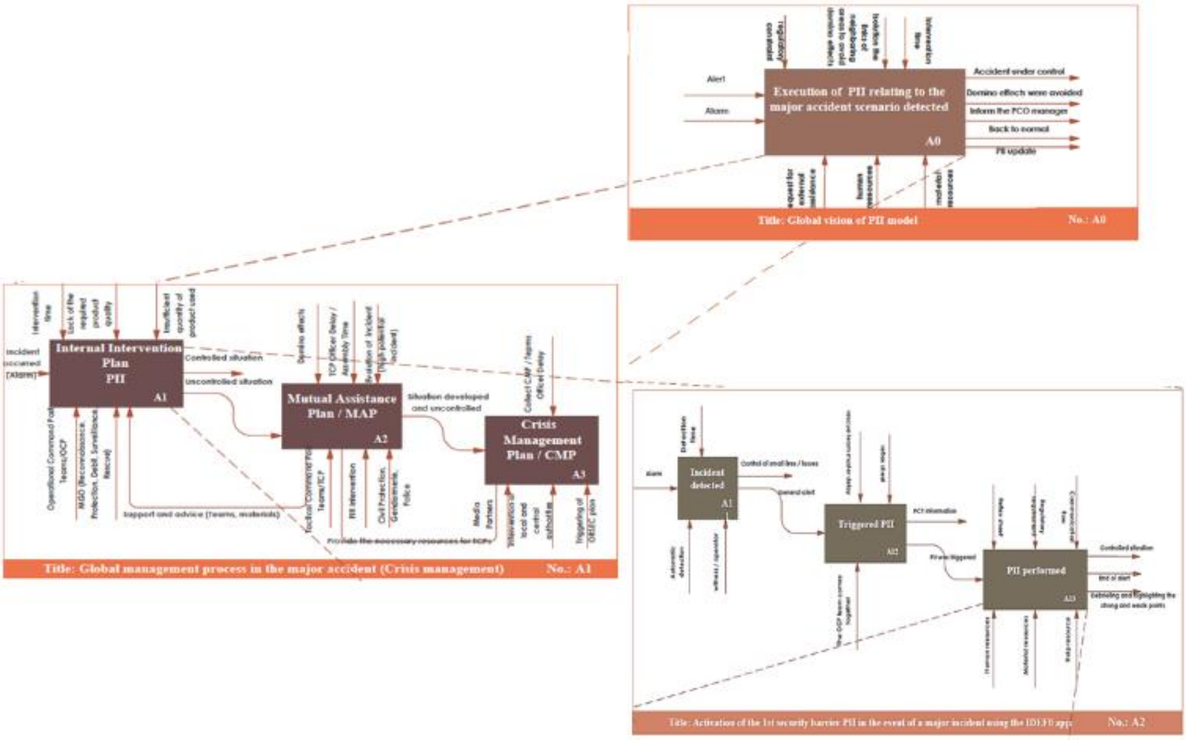

Figure 6. Modeling by the IDEF0 approach of the IIP applied to the scenario studied (fire gasoline storage tank)/ Global vision

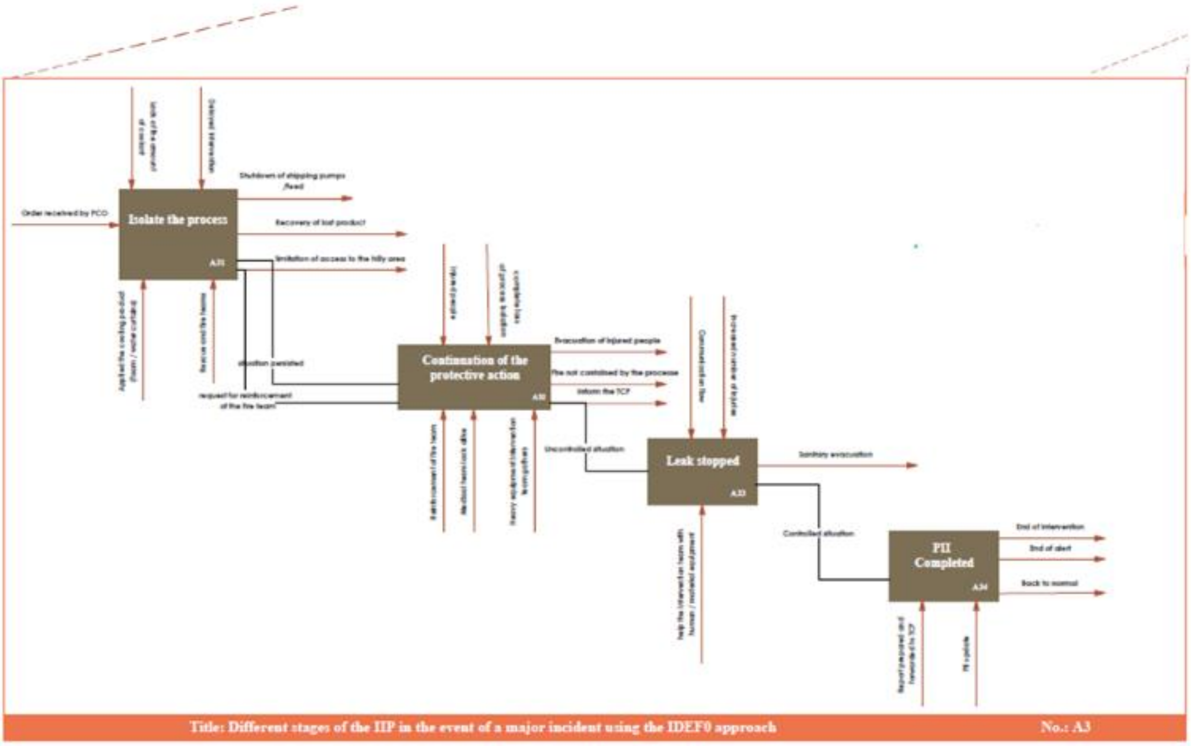

Figure 7. Modeling by the IDEF0 approach of the IIP applied to the scenario studied (fire gasoline storage tank)/Detailed vision

5.5 The BPMN model for the IIP

We used the BPMN approach to obtain a more detailed structural and functional modelling of the IIP. Then, we simulate the resulting model using bizagi software [31], a shown in Figure 8 and we obtain the Table 2 and the graph below Figure 9, which gives all the details of this plan, in particular the time necessary to carry out the task/activity for each step (examples carried out), the type of communication between these activities, and the human and material resources used necessary for each task / activity, in addition to the time of realization (key situation under control) of which:

- ✓ Detection of a leak and general alert (situation not controlled): response time relating to an accidental scenario (the execution time for the intervention) is estimated at **65 min.**
- ✓ The linear equation (in the graph) links the execution time of each task with the overall intervention time.

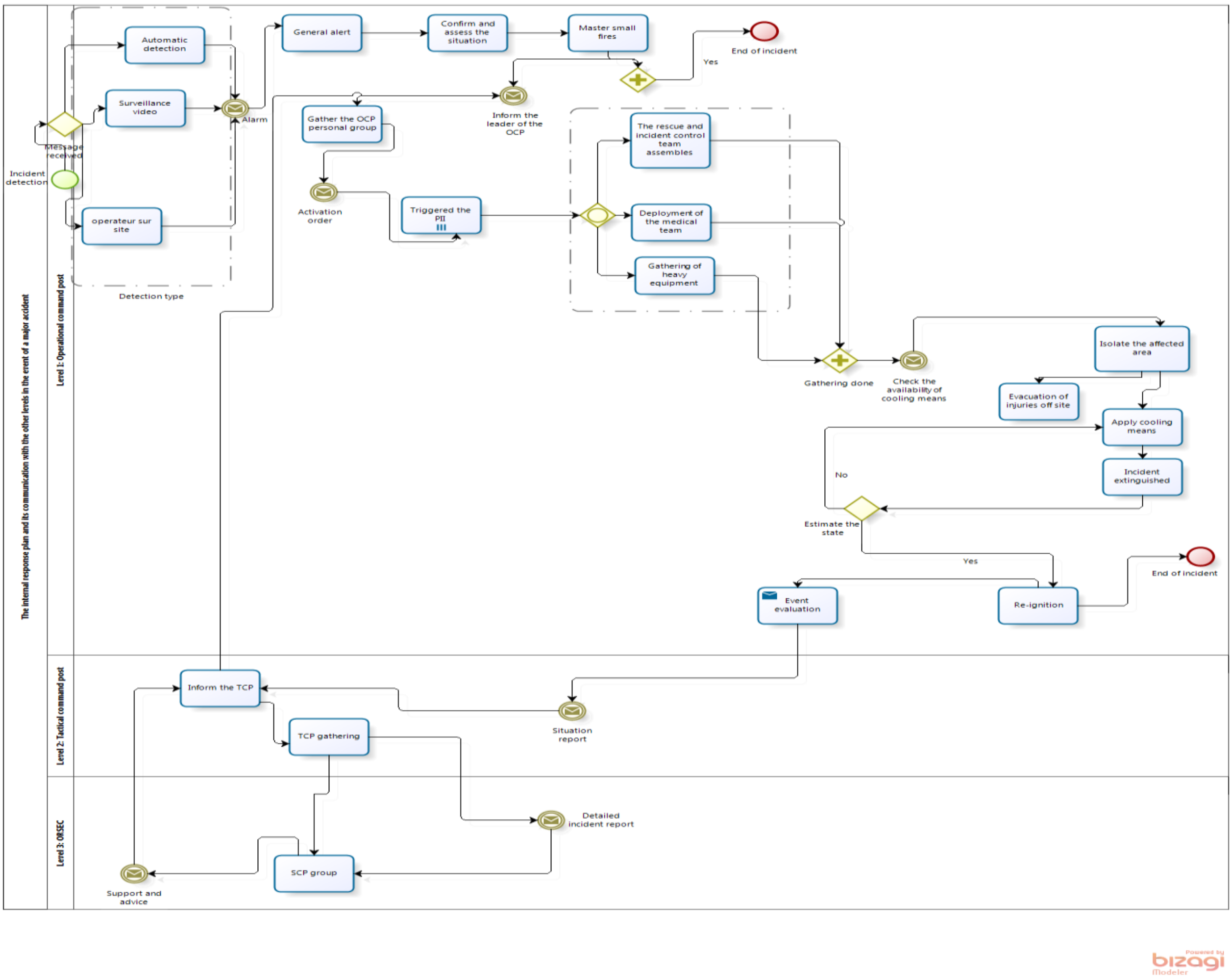

Figure 8. Modeling of the IIP applied to the scenario studied by the BPMN method

5.6 Results obtained by BPMN

Table 2. Time needed to complete the task/activity for each stage of the IIP

Name	Type	Duration of execution of each task of the internal intervention plan of a gasoline storage tank fir (Min)	human resource	material resource
The internal response plan and its communication with the other levels in the event of a gasoline storage tank fire	**Process**	**65**	**IIP**	**-**
Incident detection	Start event	**1**	-	Main room & HSE standby room
Message received	Gateway	**1**	-	talky walky/Main room & HSE standby room
On-site operator/Surveillance video/Automatic detection	Task	**1**	operator	surveillance video/phone dialing alert number
Alarm	Intermediate event	**1**	0	Main room & HSE standby room
General alert	Task	**1**	EHS department chief & informed the derogator of OCP to trigger the PII	Manual incident alarm boxes (MAI)are equipped with a pull or push button system
Confirm and assess the situation	Task	**1**	Team OCP	Fire fighting equipment with coolant

Master small fires/incident	Task	**1**	Team OCP	FIRE truck (water curtain applied)
Parallel Gateway		**1**	-	-
End of incident	**End event**	**1**	**Team OCP**	**MAI**
Inform the leader of the OCP	Intermediate event	**2**	Team OCP	Fire fighting equipment with coolant
Gather the OCP personal group	Task	**3**	Team OCP	Fire truck (water curtain applied)
Activation order	Intermediate event	**4**	Leader OCP	Fire fighting equipment with coolant
Triggered the IIP	Task	**10**	Leader OCP	Fire fighting equipment with coolant
Inclusive Gateway	Gateway	**10**	-	-
The rescue and incident control team assembles	Task	**13**	Team of rescue and incident control	Fire truck / VS truck (water curtain applied)
Deployment of the medical team	Task	**6**	doctor and nurse	ambulance
Gathering of heavy equipment	Task	**7**	heavy equipment team	reinforce FIR material
Gathering done	Gateway	**10**	-	-
Check the availability of cooling means	Intermediate event	**9**	Team of rescue and incident control	cooling product
Isolate the affected area	Task	**8**	Team of rescue and incident control	-
Apply cooling means	Task	**15**	Team of rescue and incident control	cooling product
Evacuation of injuries off site	Task	**8**	Medical team	ambulance
Incident extinguished	Task	**14**	heavy equipment team	
Estimate the state	Gateway	**14**	-	-
End of incident major/a gasoline storage tank fire	**End event**	**65**	**Team OCP**	**MAI**
Re-ignition	Task	**65**	heavy equipment team	cooling product
Event evaluation	Task	**60**	Team of rescue and incident control	-
Situation report	Intermediate event	**55**	Coordinator I	E-mail or telephone
Inform the TCP	Task	**26**	Coordinator I	E-mail or telephone
TCP gathering	Task	**33**	Teams from neighboring areas	FIRE truck / VS truck
Detailed incident report	Intermediate event	**32**	Coordinator II	E-mail or telephone
SCP group	Task	**42**	Coordinator II	E-mail or telephone
Support and advice	Intermediate event	**22**	Civil protection and teams from neighboring areas	FIRE truck / VS truck

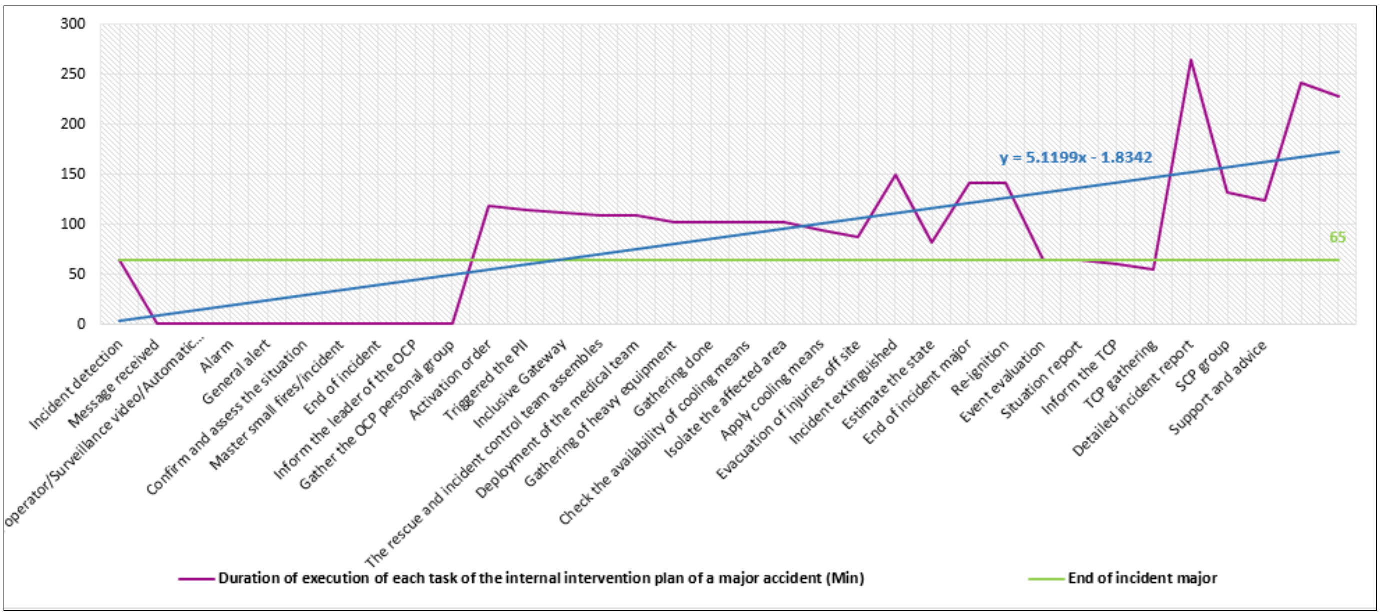

Figure 9. Average execution time of the IIP of a gasoline storage tank fire

6. CONCLUSION

In this paper we proposed a coherent approach, based on a joint use of the IDEF0 and the BPMN approaches, in order to model a specific emergency response plan called Internal Intervention Plan (IIP) that is adopted in the Algerian oil and gas industries. In fact, the modeling of the IIP allows its improvement before its execution in case of a major accident. Moreover, the proposed approach has been illustrated on a real major accident scenario related to a gasoline storage tank. Precisely, the IDEF0 approach has been used to model the structural aspects of the IIP. Based on the IDEF0 model, the BPMN one has been established in order to allow a more detailed functional modeling of the IIP. In addition, this later model has been simulated in order to estimate the different execution times corresponding to the different tasks to be performed.

However, the BPMN model does not allow considering and simulating some complicated situations especially those induced by the different dependencies that may exist during tasks execution. To overcome this limitation, more sophisticated simulation approaches such as Petri nets will be used in a future work.

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NOMENCLATURE

IIP	Internal Intervention Plan
OCP	Operational Command Post
TCP	Tactical Command Post
SCP	Strategic Command Post