Algerian Journal of Environmental Science and Technology
September edition. Vol.8. N°3. (2022)
ISSN : 2437-1114
www.aljest.org

Contribution of the structured analysis and design technique to risks management associated with loss of flame and spark misfiring in a cement furnace

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ARTICLE INFO

Article History :

Received **: 29/01/2022**
Accepted **: 29/04/2022**

Key Words:

Cement manufacturing; Failure; Prevention; Protection; Continuity of Activity.

ABSTRACT/RESUME

Abstract: *The aim of this work is the contribution of the Structured Analysis and Design Technique in the management of risks in a cement plant. By reviewing accidents that occurred worldwide, this work is contextualized. An overview of the cement manufacturing process is also provided. An approach is also developed, presented, and adopted for the conduct of this research. In addition, a presentation of the different risk analysis methods applied is given. The risk analysis approach adopted based on the use of Preliminary Hazard Analysis, Fault Tree Analysis, Event Tree Analysis, and the Bow Tie Analysis. Thus, the results of these methods will be presented and discussed. Accidents scenarios are constituted, and the most probable ones is retained. Also, and from the latter, seven risks control actions were recommended, in the critical zone of firing, without compromising the continuity of activity of the cement plant.*

I. Introduction

Industries are working hard to prevent accidents. Despite these efforts, many accidents still occur around the world. The cement industry booming in the world and offers good employability opportunities [1]. Indeed, the cement industry is present; it has become one of the best-structured and most widespread industrial activities in the world. It realizes a significant value added to the building materials industry sector. In addition, the world market economy forces the industrialists to always remain competitive. Moreover, this heavy industry requires facilities as complex as they are large to fulfill its mission. From these installations, there are a number of risks, which are predominant, arising from the potential hazards inherent in the manufacturing process, the materials used and the activities. These accident risks result in economic losses to workers, employers, and the community at various levels [2].

The operation of industrial installations is often put in default by Events is called Feared (FEs). These are directly or indirectly associated with major risks (explosions, fires, etc.) that have multiple impacts on the environment, human health and the safety of people and processes and property [3]. This implies, in part, developing performance oriented production processes and reducing costs without harming people or the environment.

The purpose of the study of accidents in the cement industry is to prepare risk analyses (RA). They also help identify the consequences of these risks. In order to reduce the probability of accidents in industrial installations safety systems are provided.

The most recent accidents related to similar industrial installations, such as cement plants, are listed in Accident Analysis Research and Information (ARIA) databases [4]. Fires and explosions have already occurred in rotary furnaces. The cement industry is mainly concerned.In addition, most of these accidents are related to the use of gas and have as causes: bad ignition procedure, Loss of Flame (LF) followed by accumulation of gas, incomplete combustion due to inadequate mixing (air/combustible gas) and unburned residues contained in the cyclone preheater. In a risk management (RM), approach feedback is a capital contribution [5]. Indeed, a synthesis of information on accidents, already occurring in similar industries, guides the search for possible malfunctions. According to ARIA, three accidents are citied [4]:

- Algeria (M'sila) in November 2013. An explosion in the cyclone line and a material leak from a door breaking the cyclone line 5 followed by a fire starter (the hot material) affecting the cables of the gas portico of the calciner and the Air-Shocks controls. As a result, the deterioration of electrical equipment has caused production to stop.
- France (Saint-Égrève), 11 June 1997. An explosion destroyed two of the four cyclones supplying a preheating furnace with natural gas, causing the refractory to be projected over a radius of 20 m. The circuit was crossed against the current by hot gases coming from the furnace. Several LF before the explosion favoured the formation of gas pockets in the upper part of the cyclones, which were not sufficiently swept through the air. As a result, a shutdown of the facility resulted in huge financial losses.
- Algeria in November 2009. An explosion due to an accumulation of gas at the cyclone tower.

The examination of these three accidents revealed that they occurred in the cooking area, where the furnace and preheat tower were the most affected areas. From the feedback of these accidents: the possibility of gas accumulation; following Feared Events (FEs) such as LF during furnace heating and Spark Misfiring (SM) after a shutdown remains to be explored to avoid major accidents.

These FEs are mainly located in the cooking line of the powder. The difficulty is to determine the causes of these events and to locate them (starting point), if the direct causes are easily identified it remains less for indirect causes.

This paper aims at the GR associated with the two FEs: LF and SM in a furnace of a cement plant to avoid their occurrence. Thus, the main objective is to secure a cement plant by analysing, assessing, and controlling the risks associated with these two FEs and preventing any loss [6].

Risk control is the final step in MR and refers to all actions aimed at reducing the probability (PL), the occurrence of an SM, or the severity (CL) of the consequences associated with a risk, deemed unacceptable. Thus, the ultimate objective is to control the risk of explosion by putting in place safety barriers (material element, safety device, instrumented safety system, etc.) [7]. In addition, three types of safety barriers are possible: Preventive barriers to avoid or limit the PO of an adverse event, upstream of the FE [8]. Therefore, prevention requires considerable financial, human and technical resources [9], Protective Barriers to limit the Impact on potential targets and limitation barriers to limit the intensity of an explosion in our case [8]. Monitoring indicators, measuring changes in the level of risk, may also recommended [10].

Accident scenarios are also designees to ensure that these risks are perfectly controlled. In addition, a methodological approach, GR, is developed, and supported by the functional decomposition type Structured Analysis and Design Technique (SADT). In addition, cost-effective risk-control measures are proposed to avoid a major accident.

II. Proposed Methodology

The proposed approach for RM is based, essentially, on the contribution of SADT for a perfect understanding of the different cement manufacturing processes. Indeed, the starting point of this work is a functional division of the entire cement manufacturing process in order to characterize the two FEs by locating them in the process. A verification of the said FEs by the deployment of a first method Preliminary Hazard Analysis (PHA) from which the critical equipment responsible (direct or indirect) for the occurrence of these FEs are identified. In addition, in their turn, this equipment's are the subject of a more in-depth analysis by three methods of analysis: Fault Tree Analysis (FTA), Event Tree Analysis (ETA), and Bow Tie (BT). Therefore, the choice of risk management solutions is taken in order to protect the targeted equipment. Figure 1 shows the main methodological steps.

III. Cement Manufacturing Process

Cement is a hydraulic Binder, finely ground Binder that, when mixed with water, forms a paste that is set and hardened by hydration reactions and retains its strength and stability, even under water. There are two main methods of cement production depending on the type of heat treatment used: wet and dry process. In this regard, cement is the product of a mixture that is fired at a temperature of up to 1450°C and is essentially composed of 80%

III.1. Steps of manufacturing

Cement production involves the use of a rotary furnace with a multi-level cyclone preheating system and a calciner [12]. Figure 2 shows the steps of cement manufacture.

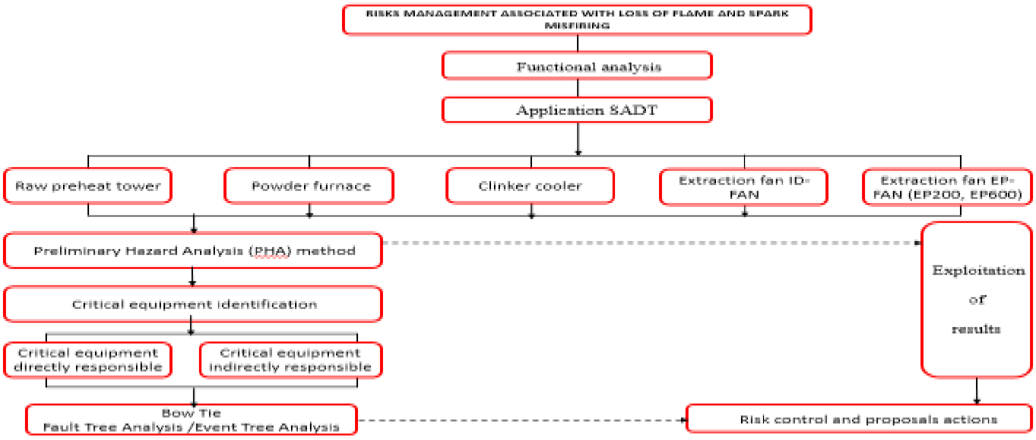


Figure 1. *RM methodological approach adopted*

Figure 2. *Cement manufacturing steps*

In fact, we distinguish four subsystems that contribute mainly to the manufacture of cement, namely as indicated in Table 1.

Table 1. *Subsystems and function*

	Subsystems	Function
1	Preheater	Preheat the raw material
2	Calcinator	Calcining
3	Burner	Burn the clinker
4	Cooler	Cool the raw

III.1.1. Cooking Shop

The two FEs studied are located in the cooking part, mainly in two systems:

- **Preheat tower**

  The hot gases formed in the furnace are drawn by a fan and circulate, at high speed, in the cyclones of the exchanger heat tower. The powder is injected at the top, descends by gravity into the five or more successive cyclones, and then penetrates a precalciner, which contains the combustion gases of the petroleum coke from the two burners located at the bottom of the tower. Then the material enters the 85-90% decarbonizedfume box [13]. The heat exchange within the tower causes: the evaporation of the free water, the release of the water constituting the clays and the partial decarbonation of the powder. An air gun system is installed at various points in the preheater to prevent clogging of any deposits of material.

- **Rotary furnace**

  Clinker is produced at 1450 ^{0}C in the furnace. The latter is a reactor in the shape of a rotating tube inclined from three to four degrees turning 3 to 5 times per minute. Heating is provided by the flame of a burner, also housing the ignition device located at the end of the furnace. Clinker combustion is the most energy-intensive process [12]. The powder, decarbonated to 95%, from the preheating tower begins its journey in the furnace at a temperature of around 1000^{0}C, is heated to the sintering or clinking (slagging) temperature of 1450^{0}C. Three zones form the furnace:

  - Zone of decarbonation (transition) locate at the entrance of the furnace corresponding to the phase of decarbonation of the raw powder to 5% with the passage of the powder from the liquid state to the solid state.

- Furnace core cooking area and the hottest part (+1500 ˚C), for the combination of $2CaOSiO_2$ with free lime to give the crystals of $3CaOSiO_2$.
- Clinking zone, the crystals leaving the cooking zone progress, grow, and granulate, thus forming clinker.

The energy required for these reactions is providing by the combustion of the natural gas considered in our case as a dangerous element.

IV. Presentation of the SADT method and application

SADT is a Functional Analysis (FA) and System Design method for understanding systems and provides tools for designing complex systems in a structured way and clearly communicating the results of the analysis. SADT is now one of the most widely used systems engineering methods [14]. Indeed, SADT defines a hierarchical functional decomposition between the different Levels of detail; decomposition at a given level reveals functions or data that are in turn decomposed. Thus, during validation, one must ensure that the entries of a function of a given level must found in its decomposition, and this must produce only the outputs of the higher-level function [15]. In addition, two elements are highlighted. First, the analysis and specification of what the system is to accomplish. Second, with what means the system achieves what is to be accomplished. To do this, the SADT uses a rectangular box-type schematization, each of the four sides of which has a special meaning as shown in Figure 3. A SADT diagram, for each hierarchical level, consists of 3 to 6 boxes for the representation to be detailed and explicit. Figure 4 shows the sequence of boxes and their relationships (inputs, outputs and controls).

Figure 3. *Actigrams*

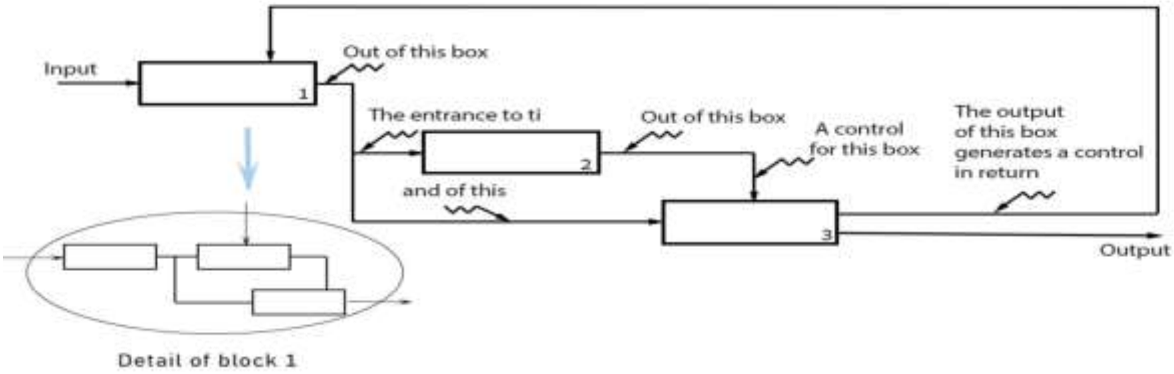


Figure 4. *Datagrams with detail at lower level [15].*

- **Application**

The identification of systems must be formalised Thus, the formalism A_0, represents the parent box symbolizing the unit of cement manufacturing grouping all the subsystems and parameters, especially the cooking area A_2, involved in cement production are illustrated in Table 2.

Table 2. *Decomposition by SADT*

<table>
<tr><td colspan="15">Cement manufacturing system - Figure 5</td></tr>
<tr><td colspan="15">Make cement A_0– Figure 6</td></tr>
<tr><td colspan="4">Subsystem A_1</td><td colspan="8">Subsystem A_2 - Figure 7</td><td colspan="3">Subsystem A_3</td></tr>
<tr><td colspan="4">Prepare the raw</td><td colspan="8">Prepare the powder</td><td colspan="3">Produce cement</td></tr>
<tr><td>A_{1-1}</td><td>A_{1-2}</td><td>A_{1-3}</td><td>A_{1-4}</td><td colspan="3">A_{2-1} - Figure 8</td><td colspan="3">A_{2-2} - Figure 9</td><td colspan="2">A_{2-3} - Figure 10</td><td>A_{3-1}</td><td>A_{3-2}</td><td>A_{3-3}</td></tr>
<tr><td colspan="4" rowspan="3"></td><td colspan="3">Preheat raw powder</td><td colspan="3">Cook the powder</td><td colspan="2">Cool the clinker</td><td colspan="3" rowspan="3"></td></tr>
<tr><td colspan="3">Reception T= 80 °C and shipment of powder T= 900 °C</td><td colspan="3">Reception of the powder preheated T= 900 °C and shipment of clinker T =1450 °C.</td><td colspan="2">Reception the clinker à T= 1450 °C. Shipment à T= 100 °C.</td></tr>
<tr><td>A_{2-1-1}</td><td>A_{2-1-2}</td><td>A_{2-1-3}</td><td>A_{2-2-1}</td><td>A_{2-2-2}</td><td>A_{2-2-3}</td><td>A_{2-3-1}</td><td>A_{2-3-2}</td></tr>
</table>

From this decomposition, a first level is formalized perfectly resuming the steps of cement manufacturing Figure 5represents the formalism A_0 and Figure 6 illustrates the main stages of cement manufacturing.

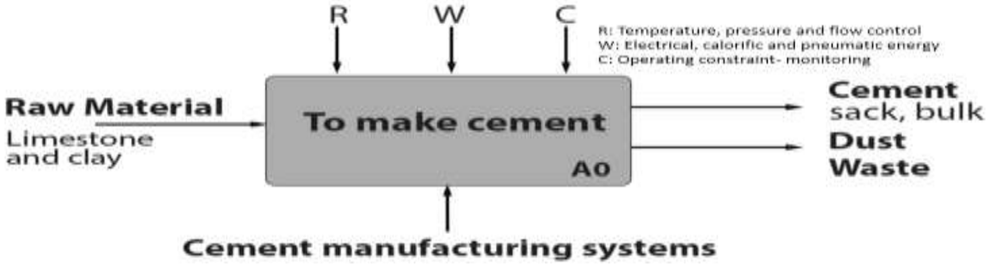


Figure 5. *SADT of cement manufacturing*

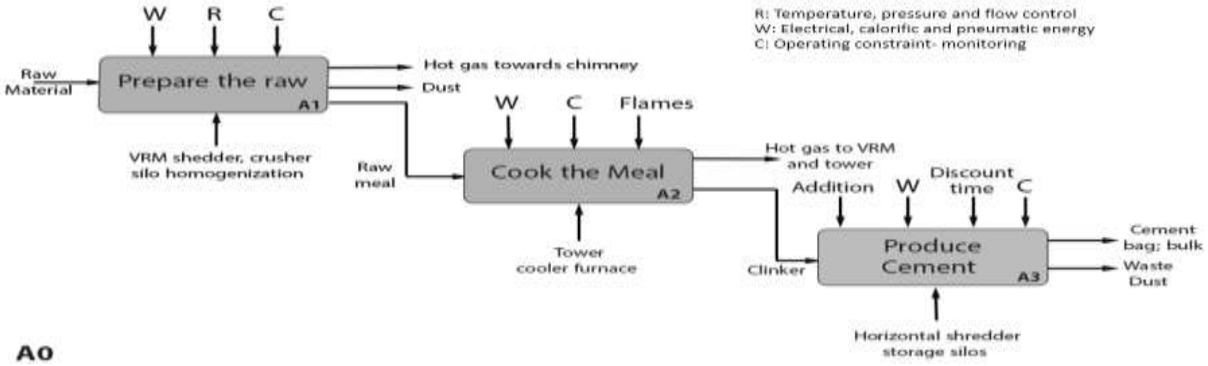


Figure 6. *SADT A_0 cement manufacturing*

Only subsystem $\mathbf{A_2}$ (cooking area), as shown in Figure 7, is broken down because of its importance in the manufacture of cement and the potential danger it represents. In addition, this system has been the seat of several accidents according to the feedback. Therefore, the Figure 8, Figure 9 and Figure 10 respectively represent formalisms $A_{2\text{-}1}$, $A_{2\text{-}2}$ and $A_{2\text{-}3}$.

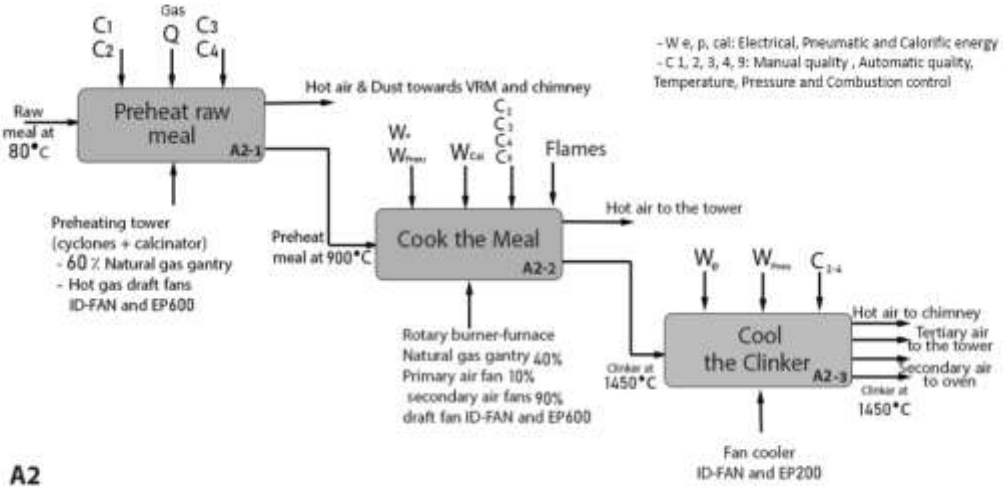


Figure 7. *SADT A_2 preparation of the raw*

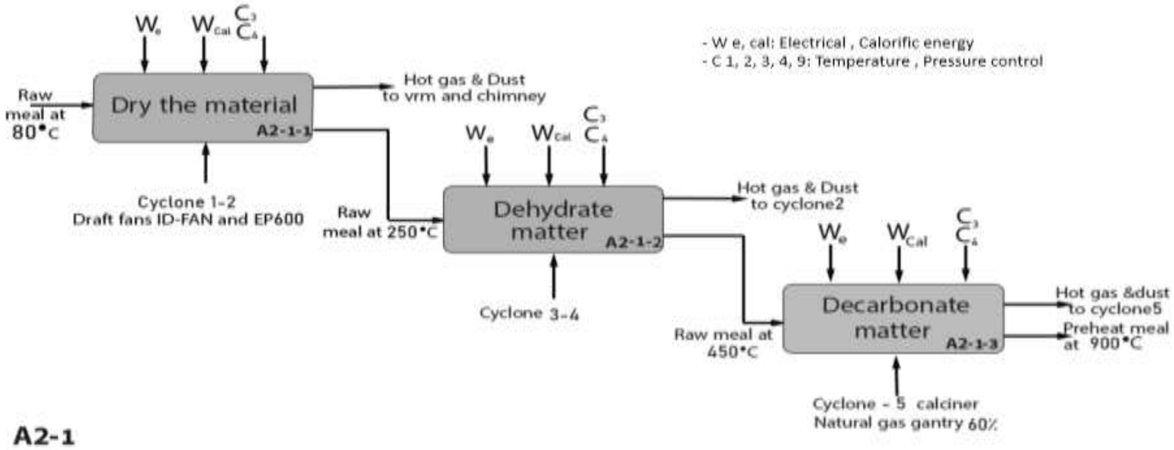


***Figure 8**. SADT A2-1 preheating of the powder*

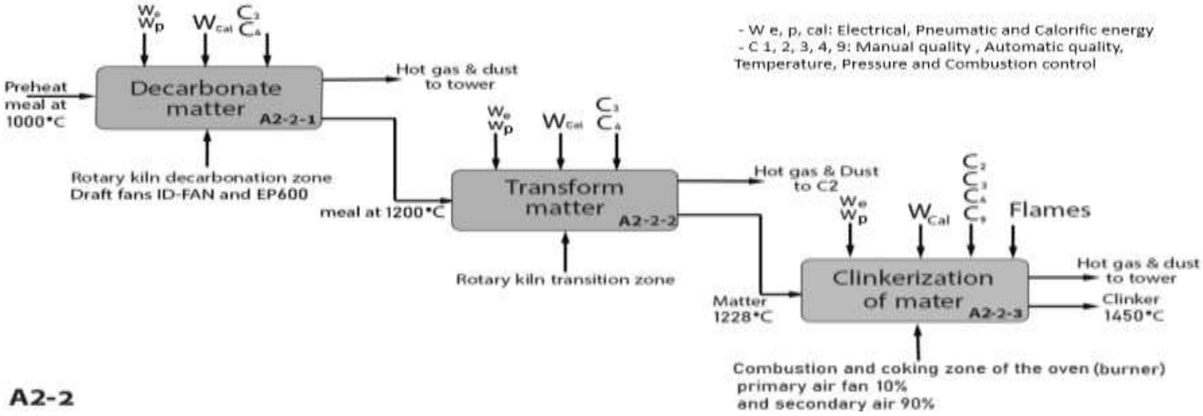


***Figure 9.** SADT A2-2 powder cooking*

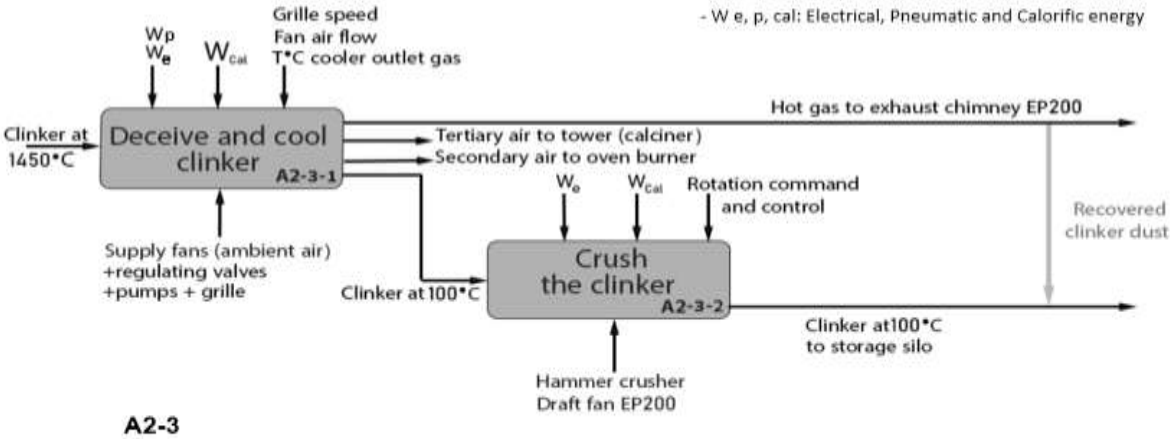


***Figure 10.** SADT A2-3 clinker cooling*

The outline of our system is perfectly delineated, and its subsystems are highlighted thanks to the contribution of SADT. Thus, this decomposition serves as a basis for the analysis of malfunctions within the cement plant. The SADT does a very precise cutting of the cement plant into subsystems, essentially the cooking line in our case. It also makes it possible to identify all the elements and

substances interacting inside.

This makes it imperative to acquire a thorough knowledge of the installation and no part is neglected. The three identified subsystems, initially, all belong to the cooking line (A_2). The remains of the two subsystems are located in the burnt gas drawing systems, since the entire installation are pressurized as shown in Table 3.

Table 3. *Cooking line and flue gas extraction subsystem*

Subsystems	Locating	
Draw line	1	Raw preheat Tower
	2	Powder furnace
	3	Clinker cooler
Burning gas draw	4	Extraction fan ID-FAN
	5	Extraction fan EP-FAN (EP200, EP600)

V. Risk Management

The RM is broken down into several steps following certain requirements to justify the implementation of risk control measures [16].It occurs throughout the life of a system[17]. Thus, RM is a process whose purpose is to prevent to secure a system or subsystem. Thus, the purpose is the control of these risks according to the operating environment that is required with decisions taken based on the comparison of the results of the risk assessment and the specified risk levels [18, 19].Figure 11 shows the four phases of RM.

Risk Analysis (RA) is at the heart of RM. It precedes the assessment to determine the acceptability of the risk, and if there is a need to control or reduce it [17]. The analysis will focus on the risks associated with the two FEs (LF and SM). The latters are known in the cement industry. It is necessary to determine the possible causes of their occurrences, which comes back to the characterized. The SADT was developed in view of the benefits it presents. Indeed, the causes of these FEs may not start from the cooking area, hence the need to explore all related subsystems. In this paper, three risk analysis methods are presented and deployed: the PHA, the FTA, the ETA and the BT the results obtained will also be discussed and recommendations will be recommended.

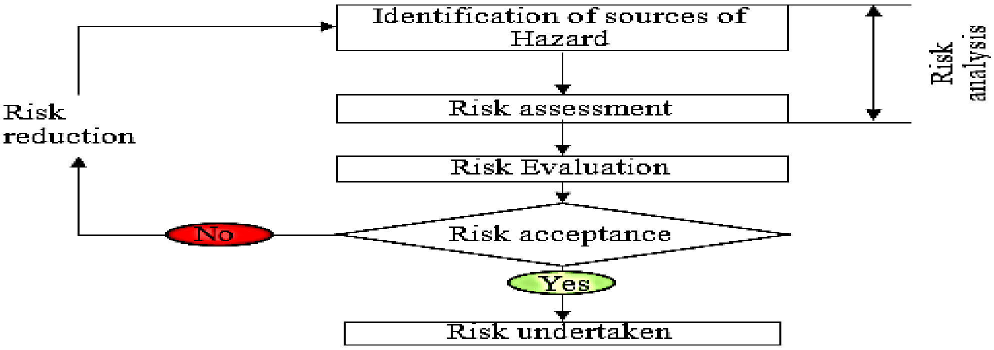


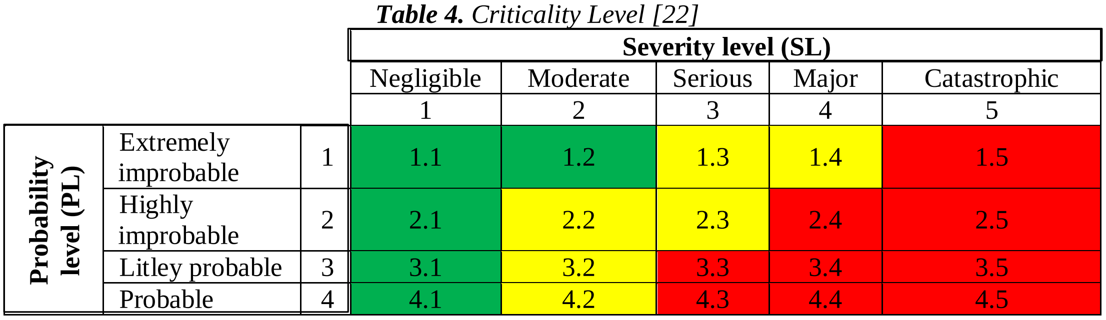
Figure 11. *RM process, adapted from [20]*

V.1. Preliminary Hazard Analysis (PHA) method

PHA is a hazard frequency identification and analysis technique that can be used in the upstream phases of design to identify hazards and assess their criticality [21]. The PHA, determines the critical subsystems, identifies the dangerous elements present in the cement plant and reveals the possible malfunctions without accurately materializing the accident. Critical subsystems are those that harbour unacceptable risks. Thus, just these subsystems were the subject of a more detailed AR (FTA and ETA) regarding the accident scenarios they were materialized by the BT method.

A risk assessment matrix is developed to confirm the presence of the causes that generate the two FEs in the cooking area. For the assessment of these risks, a Criticality Level (CL) matrix is developed, based on the various grids, as illustrated in Table 4. These grids are taken from those of the National Institute of the Industrial Environment and Risks (INERIS).

Table 4. *Criticality Level [22]*



			Severity level (SL)				
			Negligible	Moderate	Serious	Major	Catastrophic
			1	2	3	4	5
Probability level (PL)	Extremely improbable	1	1.1	1.2	1.3	1.4	1.5
	Highly improbable	2	2.1	2.2	2.3	2.4	2.5
	Litley probable	3	3.1	3.2	3.3	3.4	3.5
	Probable	4	4.1	4.2	4.3	4.4	4.5

	Highly probable	5	5.1	5.2	5.3	5.4	5.5

Criticality Level (CL) of risks obtained by multiplying the Probability Level (PL) as shown in Table 5 by the severity level (SL) as indicated in Table 6. Moreover, three types of risk are stopped, as shown in Table 7.

Table 5. *Probability level [22]*

Probability level (PL)	NP1	NP2	NP3	NP4	NP5
	Extremely improbable	Highly improbable	Littlely probable	Probable	Highly probable

Table 6. *Severity level [22]*

Severity level (SL)	SL1	SL2	SL3	SL4	SL5
	Negligible	Moderate	Serious	Major	Catastrophic

Table 7. *Risk level [22]*

Zone	**Red**	**Yellow**	**Green**
Risk level	Unacceptable risk	As Low As Reasonably Possible (ALARP)	Acceptable risk

V.1.1. Deployment and interpretations

For each SADT subsystem an assessment of the risks associated with each FE is done the analysis workflow is done according to Table 8 which represents the typical deployment of the PHA. To determine the risks according to the chosen typology, all the elements of the cooking line, resulting from the SADT cutting are examined. Table 9 shows the distribution of all risks associated with all FEs by their RL.

Table 8. *Despoilment type of PHA* [21]

PHAof a cement plant									
Subsystem (SADT)	FE	Causes	Consequences	NP	NG	NC	Prevention measures	Protection measures	Propositions

Table 9. *Breakdown with the RL*

Type of risk	Number of risks associated with the FEs	Rate (%)
Acceptable	20	59
ALARP	12	35
Unacceptable	02	06
Total	34	100

From Table 9 we note that the majority of the risks are acceptable. This is due to the existing safety measures (operational protections) in the cooking line, in particular the automated detection equipment used for checking and checking the proper functioning of the equipment. While 35% of the risks are ALARP. Finally, 6% of the risks are unacceptable. Table 10 represents a synthesis of the PHA, which essentially locates the two FEs (LF and SM) that can generate major risks.

Table 10. *Summary of the PHA*

Subsystems	Locating		Summary of the PHA
Cooking line	S1	Raw preheat tower	Loss of containment in the calciner and cyclone jam can indirectly cause LF
	S2	Powder furnace	Abrupt cracking in the burner refractory and uncontrolled combustion can indirectly cause LF or SM. Also, any anomaly in the mist directly causes the LF or a SM.

	S3	Clinker cooler	Leakage of the clinker into the trailing chain (hot air duct side to the electro filter) can indirectly cause LF or SM in the furnace. Shutting down the cooling fans can indirectly cause LF in the furnace.
Burning Gas Draw	S4	Extraction fan ID-FAN	Sudden fan shutdown causing indirect LF or SM.
	S5	Extraction fan EP-FAN (EP200, EP600)	Abrupt shutdown of one of the two fans can cause indirectly the LF or SM.

The PHA also suggests that the causes of the two FEs responsible for the majority of the risks in the cooking line do not start from the said line. In addition, only the furnace subsystem remains located in the critical zone. Thus, the occurrence of these two FEs can cause a strong explosion with production stoppages causing heavy financial losses.

V.2. Fault Tree Analysis (FTA)

The FTA in the critical zone carried out the determination of the causes of bases and intermediates, their combinations and the final probability of occurrence of an FE. The two confirmed FEs are the LF and SM.

- **Calculation of probabilities of occurrence of EFs (FL and SM) and interpretations**

Two FTAs are elaborate for the calculation of the probability of occurrence of the ERs. First FTA$_1$ of FE$_1$: LFin the furnace and the second FTA$_2$ of FE$_2$: SM in in the furnace. In addition, what is sought at this stage is to show the basic and intermediate events that contribute most to the occurrence of a given FR to propose perfectly positioned prevention barriers.

The Offshore & Onshore REliability DAta (OREDA) [23] database is used for the probability calculation of each FE. In addition, the latter is calculated from the probabilities of failure (simple and in combination) of its basic events. Thus, the calculation of the probability of occurrence (PO) of the head event (FE) and obtained by multiplying the probabilities of the basic events in the case of the gateAND. These events will be added in the presence of a gate OR [24].The probabilities of base events and barrier failures are taken from the databases [25, 26].

The calculation of the PO of the FEs: LF and SM gives respectively 1,44.10^{-2} and 1,02.10$^{-2.}$ These probabilities show that the most likely event is the LF. Also, to target the equipment contributing the most to the appearance of these two FEs. A qualitative treatment was made highlighting the following: of the FTA$_1$ we note that the failure of the drawing system is responsible for 70.83% of the occurrence of the LF, this percentage is due to the failure of 23.61% of each fan failure ID-FAN, EP200, EP600. However, from the FTA$_2$ it is found that the abrupt shutdown of EP-FAN alone is responsible for 66.66% of the occurrence of the SM, against the abrupt shutdown of the ID-FAN, which is responsible for just 33.34%.

V.3. Event Tree Analysis (ETA) and consequences

The ETA starts from a given FE and focuses on determining the resulting events and their consequences to Major Effects (ME). Thus, it allows estimating the drift of the system taking into account the elements of protection. Indeed, the analysis approach is structure around four steps as shown in Figure 12.

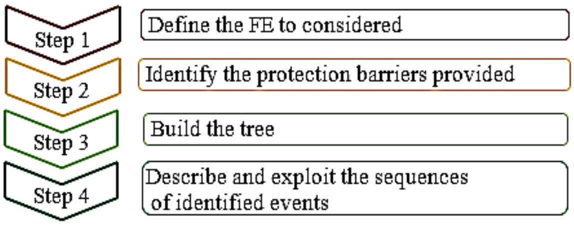


Figure 12. *Step of ETA* [27].

- **Tree development and interpretation**

The main purpose of the ETA is to calculate the probability of occurrence of explosion and fire hazards that are driven by a succession of secondary events. For this purpose, the protective barriers are identified and the calculation of the probability of their functioning and their failures is done.Thus, **Ps$_i$** represents the probability that the number i barrier will fulfil its required security function at the time t it is requested.

Similarly, **Pd$_i$** represents the probability that the barrier number i does not fulfil its security function at time t (failure at the time of solicitation). With:

$$Pd_i = 1 - P_{si} \qquad (1)$$

Two ETAs have been developed first concerns FE$_1$: LF in furnace with a PO deducted from the FTA$_1$ is equal to 1,44.10^{-2}.The second concerns the FE$_2$: SM in the furnace with a PO deducted from the FTA$_2$ is equal to 1,02.10^{-2}explosions at MEs with a PO greater than or equal to 10^{-5} have been retain. Table 11 below summarizes the eight cases of MEs explosion with their PO. The explosion EM$_{C4}$is retained and considered the most likely.

Table 11. *Location and PO of the eight explosions*

Explosion	EM$_{C3}$	EM$_{C4}$	EM$_{C6}$	EM$_{C7}$	EM$_{C11}$	EM$_{C12}$	EM$_{C14}$	EM$_{C15}$
Probability	$6,39.10^{-6}$	$\mathbf{5,18.10^{-5}}$	$7,10.10^{-7}$	$5,75.10^{-6}$	$3,37.10^{-7}$	$2,73.10^{-6}$	$3,73.10^{-8}$	$3,02.10^{-7}$
Locating	Furnace	Furnace	Furnace	Cooler and Electro filter EP200	Furnace	Electro filter EP600	Furnace	Furnace, Cyclone, Calciner and Electro filter EP600

Table 12 below summarizes the four ME explosion cases with their POs. Explosions at EM$_{C19}$, EM$_{C20}$, EM$_{C22}$ and EM$_{C23}$ are retained and considered the most likely.

V.4. Bow Tie and accident scenario mapping

After the development of different risk analysis methods, four explosion cases are then selectand summarized in Table 13.

Table 13. *Accident scenarios selected*

Scenarios	ER	Consequences	Probability	Risk	Protective barriers
1 EM$_{C4}$	LF in furnace	Accumulation of gas in furnace	$\mathbf{5,18.10^{-5}}$	Explosion in case of ignition	Flame detector Gas analyzer Safety valve Emergency stop
2 EM$_{C19}$	SM in igniter	Accumulation of gas in furnace	$\mathbf{2,38.10^{-5}}$	Explosion in case of ignition	Flame detector Gas analyzer Safety valve
3 EM$_{C20}$	SM in burner	Accumulation of gas in furnace	$\mathbf{1,93.10^{-4}}$	Explosion in case of ignition	
4 EM$_{C23}$	SM in burner	Accumulation of gas in furnace	$\mathbf{2,14.10^{-5}}$	Explosion in furnace, cyclone, calciner and electro filter EP600	

The calculation carried out brings out three scenarios of explosion in the furnace, the most frequent of which is present in Table 14. The schematization of the accident scenarios is made, by collecting the sequences from the FTAs and ETA, according to the BT method. Figure 13, Figure 14 and Figure 15 represent the three BT.

Table. 14. *Frequencies of accident scenarios selected*

Scenarios	Titled	Frequency accident $\mathbf{10^{-5}year^{-1}}$
1	Explosion following the LF in furnace.	**5.18**
2	Explosion following SM caused by failure of igniter	**2.38**
3	Explosion following SM caused by failure of burner	**0.193**

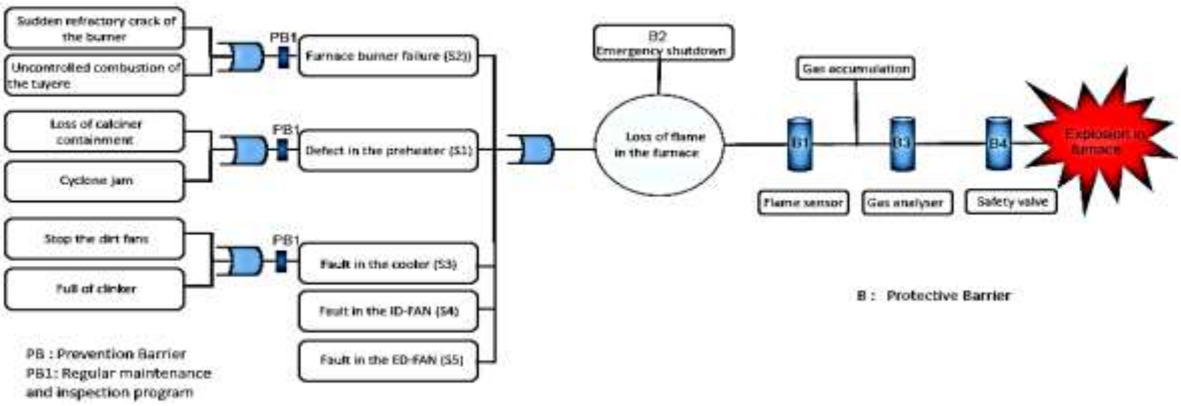


Figure 13. *Scenario n°1 explosion following to LF in furnace*

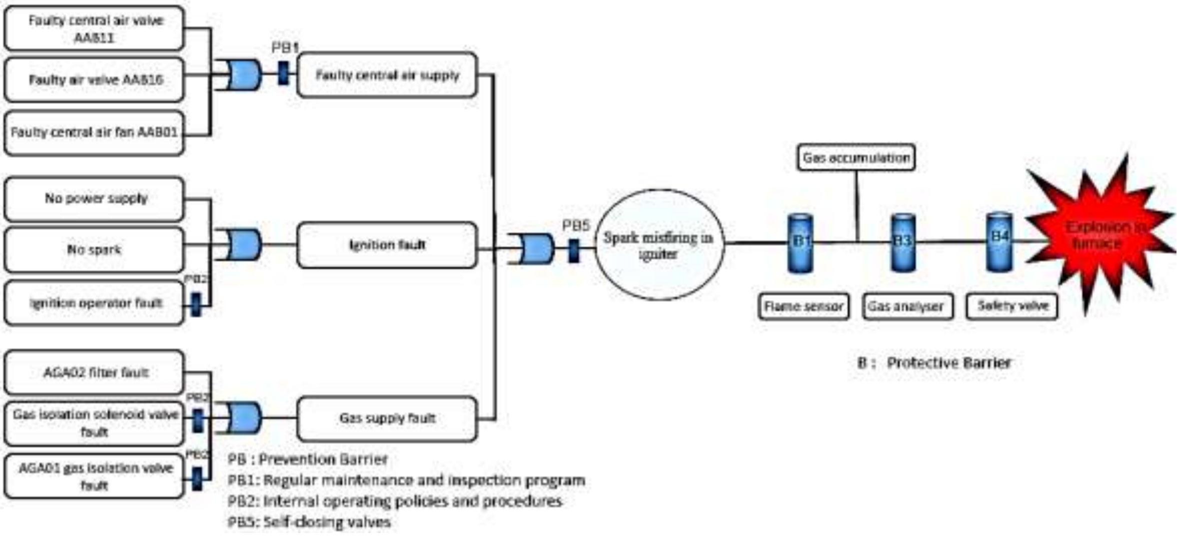


Figure 14. *Scenario n°2 explosion following to SMin igniter*

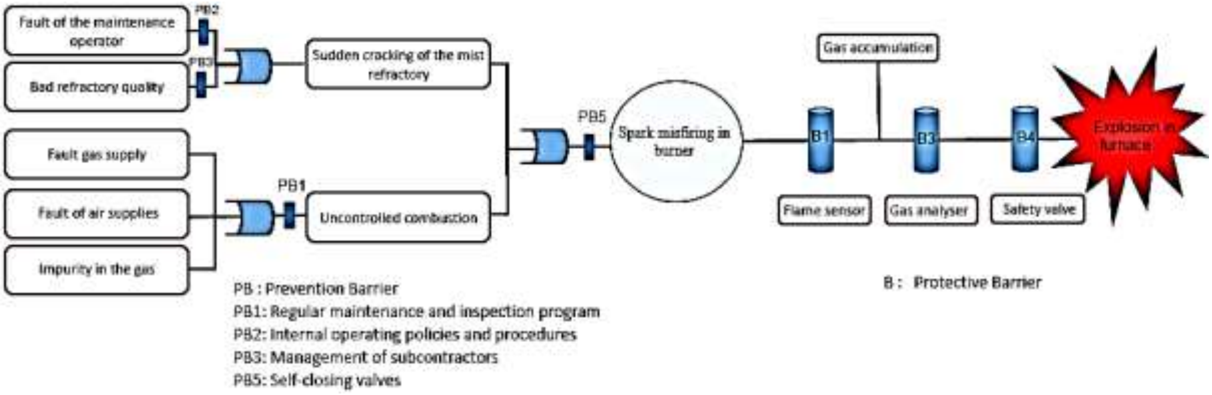


Figure 15. *Scenario n°3 explosion following to SMinburner*

The materialization of the three scenarios shows a high probability of explosion in the furnace also the chiller, electrostatic filter EP600 and EP200, and the preheater will be strongly affected. These explosions will certainly cause considerable financial losses, because the simplest intervention on the furnace requires a prolonged loss of production for six days.

V.5. Risk control and proposals actions

The results of analysis obtained, shows that prevention actions are prioritise. Indeed, the preventive solutions proposed, will not compromise the continuity of activity of the cement plant. The qualitative treatment of FTAs has highlighted the events in combination that prevail and contribute the most to the appearance of FEs. The eight components involved in the control measures are the three Draw Fans (ID-FAN, EP200 and EP600), the Burner Gas Isolation Valve (XGN14), the three Igniter Gas Isolation Valves and Valves (XGA01, XGA05 and XGA06) and the Burner Gas Regulation Valve (XGN07). Starting from FTA_1 (LF) and FTA_2(SM) preventive measures are proposed which consist in:

- Perform the redundancy of the three draw fans (ID-FAN, EP200 and EP600), for the continuity of the draw function for the cumulative gas evacuation.
- Establish a systematic type of preventive maintenance plan to increase the reliability of all gas isolation valves and other valves, the natural gas control valves that supply the burner and igniter, and the exhaust fan components (bearings, motor axes and bearings).
- Provide the cement plant with palliative electricity for continuity of the printing function.

In addition, ETA_1 (LF) and ETA_2 (SM) protective measures are also proposed which consist in:

- Install gas and fire detectors combined with an automatic general shutdown of the installations in case of alarm with equipment disconnection at the gas gantry.

- Install an automatic gas exhaust system at the fume box with a slave system that controls it connected to the control room.
- Establish a safe distance between the furnace and the rest of the cement plant infrastructure.
- Establish emergency response plans and simulation exercises on selected accident scenarios.

VI. Conclusion

This paper highlights the contribution of the SADT since it makes it possible to formalize, perfectly, all the links between the subsystems of a cement plant, and to locate perfectly the two FEs. As a result, five subsystems intervene directly or indirectly in the occurrence of the LF and the SM. In an effort to verify these FEs, the PHA has confirmed the harmfulness of the two FEs as they can generate explosion risks with considerable financial losses. Through the FTA, the two FEs were not only estimated, but also their well-identified causes. The LF is located in the link, as for the SM the failure could be either the igniter or the burner. It follows that the probability of their occurrence is FE_1: LF $=1{,}44.10^{-2}$ $year^{-1}$ and FE_2: SM $=1{,}02.10^{-2}$ $year^{-1}$. The ETA made it possible to determine the explosion accidents and their major effects. Three scenarios were selected, and their frequencies calculated. These arefirstexplosion following the LF in the link $= 0{,}52.10^{-4}$ $year^{-1}$, the 2nd: explosion following the SM in the igniter $= 2{,}38.10^{-5}$ $year^{-1}$ and finally the 3rd: explosion following the SM in the burner $= 1{,}93.10^{-4}$ $year^{-1}$. The results of these analyses allowed us to propose seven control actions. On the other hand, simulation and modeling of overpressure effects can be carried out to retain a safe distance to protect all the occupants of the cement plant.

VII. References

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Please cite this Article as:
Benmokhtar A., Zenati A., Chikouche A., Contribution of the structured analysis and design technique to risks management associated with loss of flame and spark misfiring in a cement furnace, ***Algerian J. Env. Sc. Technology,*** **8:3(2022) 2658-2670**