

The Systematic Analysis of Factors Affecting Industrial Crises Management in Process Industries Using the Fuzzy Hierarchy Process Analysis Approach

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Abstract

Background: Process industries are very complex and defective, therefore they are prone to crisis. An industrial crisis is an event with a low likelihood of occurrence but severe consequences that threatens the survival of an organization. It is described by the cause or the reasons of ambiguous and unknown solutions. It is also believed that the decisions should be made as soon as possible and not under pressure from time to time. This study was aimed to analyze and to value factors affecting industrial crisis management in the process industries through fuzzy AHP. **Methods:** This study was conducted in Tehran in 1397. Following a library study and the use of experts, a comprehensive and suitable model for managing the industrial crises was selected. A paired comparison questionnaire was developed to allow the experts to compare the elements two by two and to express the relative superiority of one to the other. Finally, by using the fuzzy hierarchy analysis method, the importance of this criteria and sub-criteria for crisis management was identified. **Results:** The results, compared with other factors in the research, showed that the crisis prevention factor had the highest relative weight (63/0). After this factors, disaster preparedness (22/0), crisis management (12/0), and post-crisis management (03/0) had the highest importance. "Risk management", "training, simulation", "identity crisis" and "assessing, correcting" were respectively the most important sub-criteria for each phases of crisis management. **Conclusion:** The present study showed that crisis prevention was the most important criterion for the effective management of industrial crises and "rapid alert inspection", "risk management" and "response to emergency conditions" were considered to be the sub-criteria. So, in order to effectively manage the industrial crisis, the managers and investors need to pay most attention to the risk management sub-criteria (the most important sub-criteria was to prevent a crisis with relative weights 44/0 compared with other sub-criteria of this factor).

Keywords: Crisis preparedness; Crisis prevention; Crisis incident management; Post crisis management

Introduction

Natural gas and oil pipeline accidents, along with the chemical industries, have been very frequent in these decades. Process industries are very complex and defective so they are prone to crisis. Indeed, the more complex the industry is, the more it is prone to a crisis.¹ An industrial crisis

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is an accident with a low likelihood of occurrence but severe consequences that threatens the survival of an organization. It is described by the cause or reasons of ambiguous and unknown solutions. It is also believed that decisions should be made as soon as possible and not under pressure from time to time.² In 2011, in a fire accident at Nairobi (Kenya) oil pipeline, 100 people were killed and about 120 people were hospitalized.³ In 2006, an explosion in pipelines in Nigeria killed nearly 500 people.⁴

The oil spill in 2010 in Mexico City (BP oil spill) on April 20, caused an explosion and a fire. The incident continued for two days, causing the oil platform to drown, leaving an oil layer at a distance of 5 miles. On April 24, oil hit the island, causing fear and flurry due to government, environmental and media attention. Over the course of several consecutive months, the government, environmental advocates, scientists and residents of the island fought oil leaks to reduce the impact of the steady flow of oil on island economics and the environment. Meanwhile, BP managers tried to react to the crisis, to protect corporate capital and profits, to manage change in leadership, to prepare for judicial and court investigations, and to save the company's public reputation. After a full-blown war with the well, finally BP announced that the well was closed and sealed on September 19th.^{5,6}

The dangers of impending crises (crises that are unlikely to happen but may eventually occur), threaten all organizations and industries in some ways. Therefore, all organizations need a type of crisis management to limit the effects of the ongoing crisis. The crisis management system in the industry is not only about preventing the crisis, but also it must be able to overcome the crisis with the least damage possible. Some researchers consider learning about past crises in order to prepare themselves to argue with

the organizations which stated that crises are the result of relatively small organizational system impairments and failures.^{7, 8} Turner in 1976 stated that when these signaling events are overlooked, they are likely to be poorly communicated and transmitted or misunderstood and interpreted, therefore, they will trigger incidents at the disaster and crisis levels.⁹ Although, Mitroff and Anagno in 2001, stated that all the crises send us warning signals, although for a short time. However, some crises such as the challenger spacecraft explosion and the natural disasters that humanity has experienced, state that man may be in crisis without warning signals.¹⁰ Based on these studies, many crises can be prevented or they will not have extensive consequences and damage if they from crises. We will learn new behaviors. In 2006 Wilding And Paraskevas argued that even in severe crises, the damage sustained by the organization, and the time for reconstruction and rehabilitation would depend on a crisis preparedness phase and an effective response to a crisis.¹¹

The explosion and fire of the Piper Alpha Oil Platform on July 6, 1988, killed 167 people.¹² The harmful effects of oil spill in 2010 on Mexico island,⁵ and other industrial crises showed the need to promote a crisis management plan, crisis prevention measures, assess crisis management systems and mitigate the effects of crises in the chemical, petrochemical, oil and gas industries. The purpose of this study was to minimize the parameters and micro parameters of the crisis management system using the Analytic Hierarchy Process and showing their significance.

Methods

This study was conducted in 2018. The method includes the following steps which are generally shown in Figure 1.

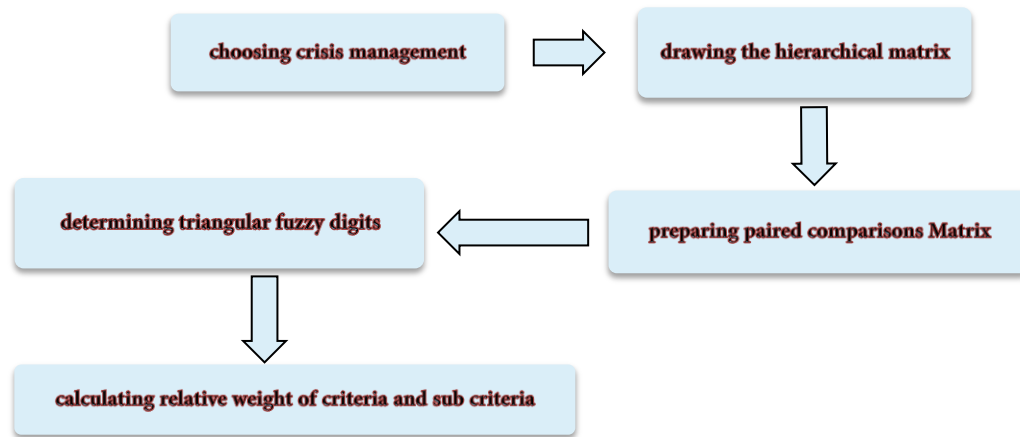


Figure 1. Steps to study

Select the appropriate crisis management model

In this study, the word crisis referred industrial crises, such as fire and explosions, and the massive release of toxic and chemical substances. Using the expert opinions(three academic experts and two experts from department of HSE Refinery Oil) and also studying articles and books related to management of industrial crisis revealed that a model should be selected which had the following characteristics:

1-It should be in a way to provide a great deal of knowledge and understanding of the crisis and it should be effective.

2- It shouldn't be linear (sequential); linearly-expressed models suggest that actions should be taken in a specific order, in order to resolve the problem. While Bigelow et al., in1993 concluded that a difficult situation does not necessarily need to be linearly (sequential path) continue, but it should go in a way that reflects the gravity of the situation.¹³

3- It should be comprehensive and integrated.

4- It should involve interaction and relationship between different parameters of crisis management.

Amongst the management crisis models presented,

the model was selected based on properties above. Therefore, from the discussions about selecting the appropriate model, they reached a consensus and finally " crises management communicative and problem " model in 2007 by Jacques (Tony Jaques) (problem and crisis management relational model) was selected.¹⁴

This model specified the interaction between different parameters of crisis management. The new model features a comprehensive crisis management that "prevention" and "preparedness against crisis" weretwo strategic phases of proactive crisis and the "response to the crisis" and "manage the crisis" were two phases of response to crisis management . The nonlinear structure of this model emphasized that the parameters should be seen as related and integrated categories, not as the steps to be done sequentially. While the two phases of pre-operational management and the response management phase had certain time relation, the parameters may be overlapped or be implemented simultaneously. For example, prevention and crisis preparedness parameters should be implemented simultaneously. Table 1 explains the definitions of the criteria and sub-criteria presented in the Jacques model.

Table 1. Definition of criteria and sub-criteria expressed in the crisis management and problem communication model

1	Planning process	Includes planning, assigning duties and responsibilities, and the crisis management process head
2	Systems and instructions	Includes risk management infrastructures ,facilities, think tanks, sources, documents
3	Training and simulation	Includes informing, testing, field and table maneuvers, simulation
4	Inspection, early warning	Includes selectiveness, preventive
5	Risk management	Includes identifying, prioritizing, determining the strategy and implementing reformative actions
6	Reaction to emergencies	Includes infrastructures, documents, training and practicing (to control early stages of crisis such as controlling small explosions)
7	Identifying crisis	Includes changing emergency into crisis, objective evaluation, early identification
8	Activation of system/reaction	Includes activation of systems(controlling and relief) mechanisms of calling other organs and support
9	Managing the crisis	Includes choosing and implementing the strategy, reducing the damage, managing the beneficiaries, responding the media
10	Recovery/ restarting the business	Operational and financial recovery, maintaining the market, starting business, and maintaining stock value
11	Post crisis effects	court investigations ,legal questions and prosecution, damage to reputation, and media scrutiny
12	Assessment and reform	Finding the root of the problem, evaluating management, reviewing the process, implementing changes

Fuzzy Analytical Hierarchy Process

In the 1980s, the Analytic Hierarchy Process was introduced for the first time.¹⁵ The Analytic Hierarchy Process, processed as a multi-criteria decision-making method, which was one of the practical ways to integrate the experts' opinions and compute benchmark scores. Finally, by decomposing the problem into smaller elements and comparing these elements together, the relative weight of each criterion or sub-criterion was determined.^{16, 17} A fuzzy number was described as a fuzzy subset of the real number.¹⁸ Triangular fuzzy numbers and trapezoidal fuzzy numbers have been widely used in some previous studies to correct the uncertainty and ambiguity of variables associated with defined topics.¹⁹ The approach of using the Analytic Hierarchy Process (Fuzzy AHP) was developed by Chang in 1996 using triangular fuzzy numbers for two-paired comparisons.

Drawing a Hierarchical Tree

Based on the criteria and sub-criteria expressed in the Jacques communication model, a hierarchical tree for the Fuzzy AHP model was drawn Figure 2.

Paired Comparison Questionnaire

In order to complete the paired comparison questionnaire, ten experienced experts (decision makers), from occupational health, safety and health HSE professionals from Tehran University of Medical Sciences (5 people) and a process industry (5 other specialists working in the safety department) were selected to do two paired comparisons(which makes possible two by two parameters).

Fuzzy Analytical Hierarchy Process

The initial form of the AHP procedure did not introduce uncertainty due to inconsistencies and ambiguities in paired comparisons. To overcome this deficiency, two paired comparisons were done at Fuzzy AHP using linguistic expressions.²⁰ In this study, triangular membership functions of fuzzy numbers have been used to reduce uncertainties and ambiguities for two paired comparisons. As shown in Fig. 3 , triangular fuzzy numbers (TFN) are often determined by using three real numbers at a distance of (1,0) denoted $\tilde{A} = (l, m, u)$. In which, m , is the median of the membership function, l and u , are the bottom and top limits of the membership function.^{16,20,22}

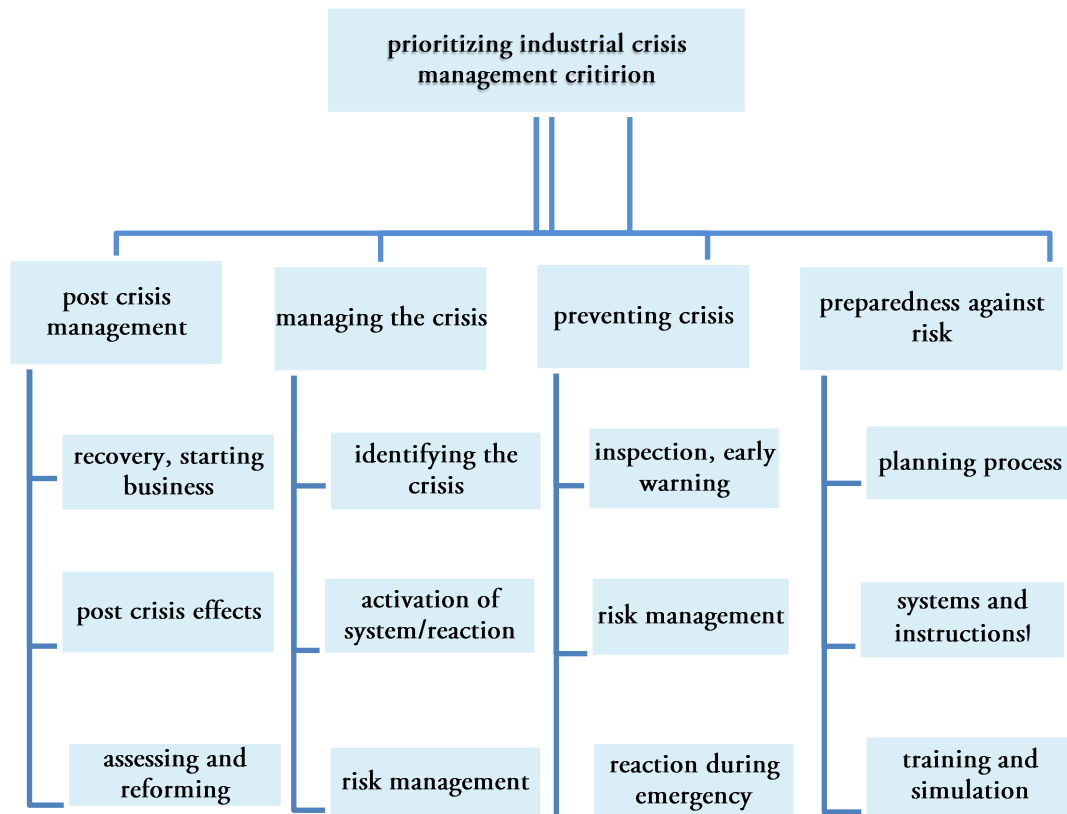


Figure 2. Hierarchical chart of industrial disaster management

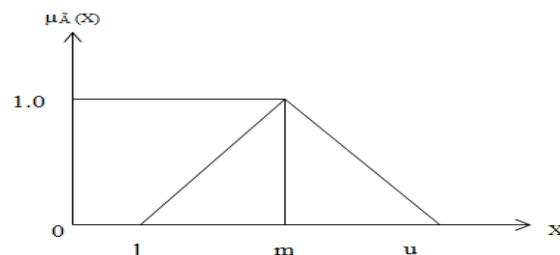


Figure 3. Membership Functions of Triangular Numbers

The relation (1) is the triangular fuzzy number (\tilde{A}) and its membership function:

$$\mu(x) = \begin{cases} (x-l)/(m-l) & 1 \leq x \leq m \\ (u-x)/(u-m) & m \leq x \leq u \\ 0 & \text{otherwise} \end{cases}$$

In this study, a 9- degree scale was used for the paired comparisons and the related triangular fuzzy sets were shown in Table 2.

Table 2. Fuzzy Spectrum Scale 9 degrees

Triangular fuzzy number	Verbal phrase	Importance
(1,1,1)	Equally important	1
(1,2,3)	Midway	2
(2,3,4)	Slightly more important	3
(3,4,5)	Midway	4
(4,5,6)	Relatively more important	5
(5,6,7)	Midway	6
(6,7,8)	Much more important	7
(7,8,9)	Midway	8
(8,9,9)	Absolutely more important	9

Table 3. Relative weights of criteria and sub-criteria

Relative weight	Sub-criteria	Relative weight	Metrics	Relative weight	Sub-criteria	Relative weight	Metrics
0.36	Identify the crisis	1.2	Management in the event of a crisis	0.29	Quick Alert, Inspection risk management	0.63	Prevention of crisis
0.31	Answer / Activate Systems			0.44	Response to Emergencies		
0.33	Crisis management has taken place			0.27	Planning process		
0.41	Recover, resume business	0.3	Post-crisis management	0.24	Systems, instructions	0.22	Preparedness for the crisis
0.15	After-crisis effects			0.30	Training, simulation		
0.44	Evaluation, correction			0.46			

To quantify the results of the experts' survey, relation 2 was used:²⁰

Buckley suggested the following equation to determine the fuzzy geometric mean method, the weight of each criterion.²³ The defuzzing technique was used to convert fuzzy numbers to logic numbers; the defuzzing process should be the best non-fuzzy function.¹⁶ Different ways were available for this purpose, for example, the maximum mean, the center level and the middle method.²⁴ In this study, the surface center method was used. The relation 4 was used to obtain the defuzzed number of the fuzzy numbers.¹⁶

The Compatibility Index (CI), in order to calculate any incompatibility in the paired comparison matrix and the compatibility rate (8), in the following relations were calculated.^{21,25} That λ_{\max} was the largest special matrix value, n , Matrix dimension and RI the random inconsistency index which depends on "n". Comparisons were less than or equal to 0.1 if the comparisons were consistent.²⁵

Findings

In this paper, the Analytic Hierarchy Process was used to determine the weight and the importance of the criteria and the sub-criteria of the effective industrial crises management. Fuzzy evaluation using the comments of the experts' in the field of safety and crisis management was done. Compliance rate for this study was obtained from

0.81/0. Values less than 0.1 were accepted. Table 3 shows coefficients for each of the criteria and sub-criteria to show effective crisis management.

According to this table, "crisis prevention", had the maximum amount (6.3/0). Relative Coefficients about the sub-criteria to prevent crises were 4.4/0 for the risk management, 2.9/0 for the early warning and monitoring, and 2.7/0 to respond to emergencies. Risk management was of utmost importance in all 12 sub-criteria, because the most important fuzzy criteria of crisis prevention (4.4/0 6.3/0) had the relative coefficient of 27.72/0. Crisis preparedness (with a relative coefficient of 0.22) took the second place. Training, simulation, systems, procedures and criteria for this phase of the planning process under which the relative coefficients were 4.6/0, 3.0/0 and 2.4/0 related to them. The third important factor in terms of crisis management, was of course the most important factor of fuzzy reactive crisis management with the relative coefficient of 1.2/0. The following criteria in the order of importance of these factors included: the identification of the crisis with relative coefficient of 3.6/0, and crisis management with the relative rate of 3.3/0, response / partial activation of the system by a factor of 3.1/0.

Besides, the crisis management factor was the least effective crisis management (with a relative coefficient of 0.3/0) and had three sub-criteria which evaluated modification with the relative coefficient

of 4 4/0 which was the most important factor. Sub-criterion of starting business, with a relative coefficient of 0.41 was the second sub-criterion and ultimately the sub-criteria of the post-crisis effects with a relative coefficient of 0.15 was the least important. This sub-criteria was the least important sub-criteria (by a factor of 03/0 * 15/0) in all 12 sub-criteria for crisis management (by a factor of 00 4 5/0).

Discussion

There are major hazards in process industries. In the past decades, the industrial crisis (such as a fire or explosion, chemical and toxic spill) have increased.²⁶ The present study aimed to determine the importance of crisis management variables in complex industries using the fuzzy AHP approach.

This study showed that the "crisis prevention" phase, the most important phase in the crisis management industry, was in the process industries (with the relative weight of 6 3/0). Prevention of a crisis was a set of measures aimed to prevent crises or to reduce their harmful effects. It also assessed the risk level of the organization and reduced the risk level to an acceptable level with the necessary studies and measures (14). This phase of crisis management consisted of three sub-criteria; rapid alert, risk management and emergency response. Despite the fact that this study showed that its management should pay more attention to the "prevention" phase", in practice it preferred focus on other phases of crisis management. While it was not possible to anticipate all the problems and scenarios²⁷ {Weick, 2008 # 3; Weick, 2008 # 3} but the evidence suggested that most crises were due to the involvement of managers with events that were predictable but were neglected.²⁸ Therefore, organizations faced significant costs that could be prevented or at least significantly reduced. Hence, understanding, confronting and preventing preventable crises were the major challenges for researchers.²⁹ Smith in 1990, stated that one of the

reasons that crisis prevention was severely ignored in countering readiness and response to the crisis was that the phase of "prevention" poses fundamental questions about the nature of management style and organizational culture. Smith suggested that this is mostly because managers were afraid of changes that brought these questions to themselves.³⁰ An effective preventive process was essentially needed to carefully examine the environment, to collect information, to evaluate and analyze this information and turn it into corrective action. Risk management provided an integrated framework for this process.³¹ The relative weight for the risk management with the relative weight of 4 4/0 in this study was the criteria with the most important phase of "prevention". An effective crisis management system started with the risk management and an efficient problem.³² The second sub-criteria of "prevention", the early warning phase, was to monitor with the relative weight of 2 9/0. This included audits, preventive maintenance, inspection and prospective management. The last but not the least sub-criterion of the preventive phase to prevent industrial crisis was "Responding to emergencies" with the relative weight of 27/0. Emergency response is an important factor in the phase of crisis prevention, because it will lead to a crisis if the emergency situation is not well controlled.³³ Emergencies are referred to as early stages of the crisis, such as: small fires and small and initial leaks.¹⁴

The second important criterion in the eyes of experts, the phase of "disaster preparedness" is with the relative weight of 22/0. Jacques in 2007 defined preparedness for the crisis as a set of actions that increases the organization's ability to perform various stages of crisis management, including process planning, systems and procedures, training, exercises and simulations.¹⁴ Given that crises today are inevitable parts of labor and industry,^{34,35} industries need to be prepared to deal with them. The most important sub-criteria for this phase were

"training, simulation" with relative weights of 4 6/0. The American Management Association reported that only 49 % of the organizations surveyed, had crisis planning, and only 39 % had done a maneuver or simulation.¹⁴ Considering the importance of training and simulation factors, it is essential to introduce familiarization programs, training classes and perform various types of maneuvers and simulations for the industry. The second factor in this phase was "system instructions" with relative weight of 30/0. Systems and instructions are essential and in fact are essential for effective crisis management. But such systems and procedures can trick an organization thinking that it is "ready to deal with the crisis".¹⁴ The research done by Marra (1998) showed that the existence of this fundamental factor had little effect on the outcome of some known crises.³⁶ "Planning process" with the relative weight of 2 4/0 was the last sub-criterion of the preparation phase. Several studies have shown that a disappointing percentage of companies have a crisis management program - usually about 50 percent - and a smaller percentage have evaluated it as if it is operational and appropriate.³⁷ while Mitroff and Pauchant³⁸ have identified more than 30 different justifications that managers have expressed for not planning appropriately, it is clearly shown that when a crisis reaches an organization without an operational crisis management plan, the crisis will take much longer.³⁹

"Management during the crisis" with relative weight of 1 2 /0 is the third important criterion in the risk management process. The performance of the emergency services and services in response to a crisis, which is aimed at saving lives and preventing damage spread, is called crisis management, which includes crisis detection, system activation, and crisis management.¹⁴ This study showed that "identifying crisis" is the most important criterion for this phase with the relative weight of 36/0. Sometimes management can't interpret the symptoms easily,⁴⁰

and sometimes even ignore the early alerts.⁴¹ Detecting and recognizing a crisis may seem simple and clear, but the reality is very different. As Fink³⁹ warned: "As a general reality, you should almost accept that when a crisis is taking place, it may be accompanied by misleading issues". As a manager, your job is to identify the real crisis. The second sub-criterion of the management phase during the occurrence was "crisis management" (with a relative weight of 0.38), which consisted of choosing and implementing a strategy to reduce harm, beneficiary management, and media response. Many studies have discussed the existence of operational programs and checklists that have the necessary information to select and implement an effective strategy.¹⁴ The last sub-criterion was "response / activation systems" with the weight of 3 1 /0, which indicated the activation system should be done quickly and effectively.

The last phase of the crisis management presented in Jacques communication model, which had the least importance (with a relative weight of 0.03), was "post-crisis management" and it is related to the necessary measures after the crisis, which include the recovery and starting business, post-crisis effects, and assessment and reform.¹⁴ "Evaluation, reform" with the relative weight of 4 4 /0, "recovery, starting business" with the relative weight of 41/0 and "the effects of the crisis" with relative weight of 15/0 were respectively sub criteria of post crisis management phase. The end of each crisis should be to begin a preparation step for the next crisis. Penrose³⁷ argued that companies that have experienced a crisis were more likely to be prepared for future crises. After any crisis, there is a rational request to move as quickly as possible in order to resume business.

Conclusion

This study, used fuzzy hierarchical analysis (FAHP) to determine the importance of industrial crisis management variables in process industries.

The present study stated that prevention of crisis was the most important variable in the management of industrial crises in process industries. Therefore, process industry managers should focus their attention on the prevention phase, which not only creates a hope for industry, but also places their industries in a more or less secure way rather than other industries that do not focus on the prevention phase of the crisis. thus it creates a pride, a reason for mobility and perseverance to continue the lifecycle.

Risk management was the most important sub-criterion of crisis prevention phase, training, simulation was the most important sub-criterion of crisis preparedness phase, crisis identification was the most important sub-criterion of the crisis management phase, and assessment, reform was the most important post-crisis management sub-criterion. The fuzzy hierarchy analysis process, using experts' opinions, was a useful tool for prioritizing and evaluating the variables of industrial crisis management, which enabled the introduction of the most important variables to manage industrial crises in the process industry.

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