Mathematical and statistical modeling of industrial accident consequences in Algeria: A Systematic Review from 2003 to 2023

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Abstract
Industrial accidents pose significant challenges to the safety and well-being of workers, communities, and the environment. In Algeria, as in many developing countries, these incidents have garnered increased attention due to their potential socio-economic and environmental ramifications. This systematic review aims to provide a mathematical modeling and statistical analysis of industrial accident consequences in Algeria over the period spanning from 2003 to 2023.

The systematic review begins by outlining the major industrial sectors in Algeria, their growth trends, and the key contributing factors to industrial accidents. It then delves into a meticulous analysis of the mathematical and statistical methodologies employed in consequence modeling, including dispersion modeling, explosion modeling, and risk assessment techniques. The study identifies key challenges and limitations in the existing literature, highlighting the need for improved data collection, model validation, and regulatory measures.Furthermore, this review explores the impact of industrial accidents on human health, the environment, and the economy in the Algerian context. It assesses the adequacy of current safety protocols and regulations and suggests potential areas for enhancement.

Through a comprehensive analysis of the literature, this review provides valuable insights into the state of industrial accident consequence modeling in Algeria, identifies research gaps, and offers recommendations for future research and policy development.

The findings of this review contribute valuable insights into industrial accident management and prevention strategies in Algeria and serve as a foundation for evidence-based policymaking. By comprehensively examining the trends, determinants, and consequences of industrial accidents, this study addresses a critical knowledge gap and offers a robust framework for enhancing workplace safety, safeguarding communities, and preserving the environment.

Keywords: Industrial accidents, mathematical modeling, statistical analysis, consequence modeling, workplace safety, Algeria,

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1. Introduction

Industrial accidents pose significant challenges to both human lives and the environment, making them a subject of critical concern worldwide[1, 2]. The consequences of these incidents can range from immediate and localized effects to long-term, far-reaching impacts that affect communities, economies, and ecosystems[3]. To address the complexity of industrial accidents and their consequences, numerous studies have been conducted globally to develop models and methodologies aimed at understanding, predicting, and mitigating the adverse outcomes of such incidents[4-6].

In the early stages of industrial accident modeling, researchers focused on improving modeling capabilities and understanding the consequences of accidents[7]. D.C. Aldrich et al. (1982)[8]reviewed the developments in nuclear reactor accident offsite consequence analysis, emphasizing improvements in modeling capabilities and their application in decision-making processes. Chang Sun Kang and Sae Yul Lee (1984)[9] introduced a novel approach by applying the Monte Carlo method to evaluate the potential risks from nuclear facilities following accidents. Their work incorporated on-site meteorological data, contributing to a more accurate assessment of radiological consequences.

Sarbes Acharya and L.G. Hulman (1984)[10] discussed the U.S. Nuclear Regulatory Commission's (NRC) role in conducting reactor accident consequence assessments. They outlined the use of the CRAC code and the importance of site-specific code inputs in making probabilistically related safety judgments. R. Cooke (1994)[11] contributed to the field by applying structured expert judgment methods to assess uncertainty in accident consequence analysis for nuclear power stations. This work served as a pilot study, revealing the need for a more comprehensive understanding of key parameters and uncertainties in consequence modeling.

In the context of fusion power plants, N.P. Taylor et al. (1995)[12] outlined a sequence of calculational methods to analyze the consequences of hypothetical upper-bound accident scenarios. Their work integrated various models to assess nuclide inventories, temperature histories, and atmospheric dispersion. M.R. Yeung and W.S. Lui (1997)[13] presented an efficient wind-field model (HKWIND) for analyzing nuclear accident consequences. They emphasized the importance of including wind-field models in dispersion analyses, significantly impacting outcome frequencies for various consequences.

B.C.P. Kraan and R.M. Cooke (2000)[14] discussed the construction of distributions for code input parameters using structured expert judgment methods. They highlighted the significance of considering correlations in uncertainty analysis, providing insights into more accurate modeling. W.E. Han (2003)[15]explored refinements in consequence modeling for hypothetical accidents in fusion power plants. By introducing more realistic treatments for aerosol modeling and wind meandering, this research aimed to reduce conservatism in previous calculations.

Accident databases have played a crucial role in understanding accident frequencies and severities. A. Meel et al. (2006)[16] and A. Bernatik et al. (2008)[17] utilized these databases to analyze and model the consequences of accidents in chemical plants and hazardous substances transportation.

Recent studies have continued to advance the field of industrial accident modeling. R. Parvizsedghy and S.M. Sadrameli (2014)[18] investigated the consequences of accidents in supercritical biodiesel plants, emphasizing the importance of safety measures and protective strategies. A. Al-Shanini and F. Khan (2014) conducted a study focusing on accident modeling in the chemical process industry, with a specific emphasis on dynamic sequential accident models (DSAMs). T. Gélain, A. Rondeau, S. Peillon, J.C. Sabroux, F. Gensdarmes (2015) [19] investigate dust resuspension during a loss of vacuum accident (LOVA) in the ITER tokamak. It analyzes factors affecting dust mobilization, providing insights into the risks associated with dust resuspension in nuclear fusion facilities. V.A. Korchagin, A.N. Novikov, S.A. Lyapin, I.A. Novikov, and V.A. Konovalova (2016) [20] Focusing on traffic accidents, their study proposes a comprehensive approach to managing the consequences of such accidents. It identifies key factors impacting traffic accident consequence management within a socio-natural-economic system. Çetinyokuş (2018) [21] conducts a consequences analysis of the Akçagaz LPG Facilities accident, particularly in loss of containment (LOC) scenarios. It evaluates different land use

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planning (LUP) methodologies and modeling approaches to assess the accident's impact.M. Bogalecka (2019)[22] introduced a probabilistic model for critical infrastructure accident consequences. The model considered initiating events, environmental threats, and environmental degradation, offering insights into cost analysis and risk reduction strategies. A. Soltanzadeh and I. Mohammadfam (2022) [23]conducted a retrospective study on occupational accidents in construction sites. They employed structural equation modeling to identify the causes and consequences of accidents, highlighting the impact of safety training and risk assessment. M. Wu et al. (2023) [24]addressed the dispersion of hazardous chemical gases during accidents. Their study utilized Computational Fluid Dynamics to model the dispersion, exposure risks, and mortality rates associated with chemical leaks.

It's essential to note that while the studies presented here represent notable contributions to the field, they do not encompass the entirety of research carried out on industrial accident modeling. Instead, they serve as exemplars of key advancements in the discipline.

These studies provide valuable insights for researchers and practitioners seeking to enhance safety measures and mitigate the risks associated with industrial accidents.

While the international literature on industrial accident modeling has expanded significantly in recent decades, it is essential to focus on specific regions to tailor effective safety measures and response strategies. This paper presents a comprehensive literature review of industrial accident consequences modeling studies conducted in Algeria between 2003 and 2023. By narrowing our scope to the Algerian context, we aim to provide insights into the unique challenges and circumstances facing this North African nation.

The significance of studying industrial accident consequences in Algeria cannot be overstated. Algeria boasts a diverse industrial landscape, with sectors such as oil and gas, petrochemicals, mining, and manufacturing playing pivotal roles in the country's economy. The growth of these industries has led to increased industrial activities, thereby raising the potential for accidents and their subsequent consequences. Understanding the specific dynamics of industrial accidents in Algeria is vital for enhancing safety protocols, disaster preparedness, and response strategies within the country.

This literature review draws on a wide range of highly-ranked journals, research articles, and scholarly works to provide a comprehensive overview of the state-of-the-art in mathematical and statistical modeling of industrial accident consequences. It offers an analysis of the methodologies, models, and findings from previous studies, shedding light on the lessons learned and gaps that warrant further investigation. By synthesizing this wealth of knowledge, we aim to provide a valuable resource for researchers, policymakers, and industrial stakeholders seeking to improve safety practices and disaster management in the Algerian context.

In the subsequent sections, we will delve into the specific methodologies employed in the reviewed studies, discuss key findings, and identify areas where further research is needed. By doing so, we hope to contribute to the ongoing efforts to minimize the risks associated with industrial accidents in Algeria and ensure the safety and well-being of its citizens.

2. Methodology

2.1. Inclusion and Exclusion Criteria

Our systematic review aimed to identify and analyze studies related to mathematical and statistical modeling of industrial accident consequences in Algeria. Release time or period articles published in peer-reviewed journals from 2003 to the end of 2023 were included in this study. All related research articles (original articles) were reviewed, conference papers were also excluded from this study. Papers that used modeling methods to assess the consequence of accidents were reviewed if they had a full text, and the results of the study were mentioned, and papers that did not have a full text were deleted. The research question was related to the mathematical and statistical consequence modeling of accidents or incidents in the industrial sectors.

The following inclusion and exclusion criteria were applied to select relevant studies:

- Studies conducted in Algeria or focused on industrial accident modeling in Algeria.
- Studies published in peer-reviewed journals, conference proceedings, or technical reports.
- Studies available in English or French, as these are the primary languages of scientific literature in Algeria.
- Studies published between the years 2003 and 2023 to capture the most recent developments.

The exclusion Criteria of the study are:

- Studies not related to industrial accidents or mathematical/statistical modeling.
- Studies lacking essential data or methodology descriptions.
- Duplicate publications or studies without full-text access.

2.2. Search Strategy

A comprehensive search strategy was developed to identify relevant studies. The following databases were systematically searched:

- Web of Science
- Scopus
- Google Scholar
- IEEE Xplore
- PubMed

2.3. Study Selection Process

The study selection process involved multiple stages:

- Initial screening: Titles and abstracts of retrieved articles were screened for relevance to the research topic.
- Full-text assessment: Articles passing the initial screening were assessed in full text to ensure they met the inclusion criteria.
- Data extraction: Relevant data, including study objectives, methodology, mathematical models, and statistical techniques, were extracted from the selected studies.

2.4. Data Extraction

Data from the selected studies were systematically extracted and recorded in a structured Table. The following information was collected:

- Title, authors, and publication details.
- Objectives and research questions.
- Methodological details, including the mathematical and statistical models used, method, used software, etc.
- Key findings, conclusions, and limitations related to industrial accident consequences modelling in Algeria.

2.5. Data Synthesis

Data synthesis involved a qualitative analysis of the selected studies. Key findings, trends, and commonalities among the mathematical and statistical models used in the context of industrial accidents in Algeria were summarized and synthesized. This process aimed to provide a comprehensive overview of the state of research in this field (See Fig. 1).

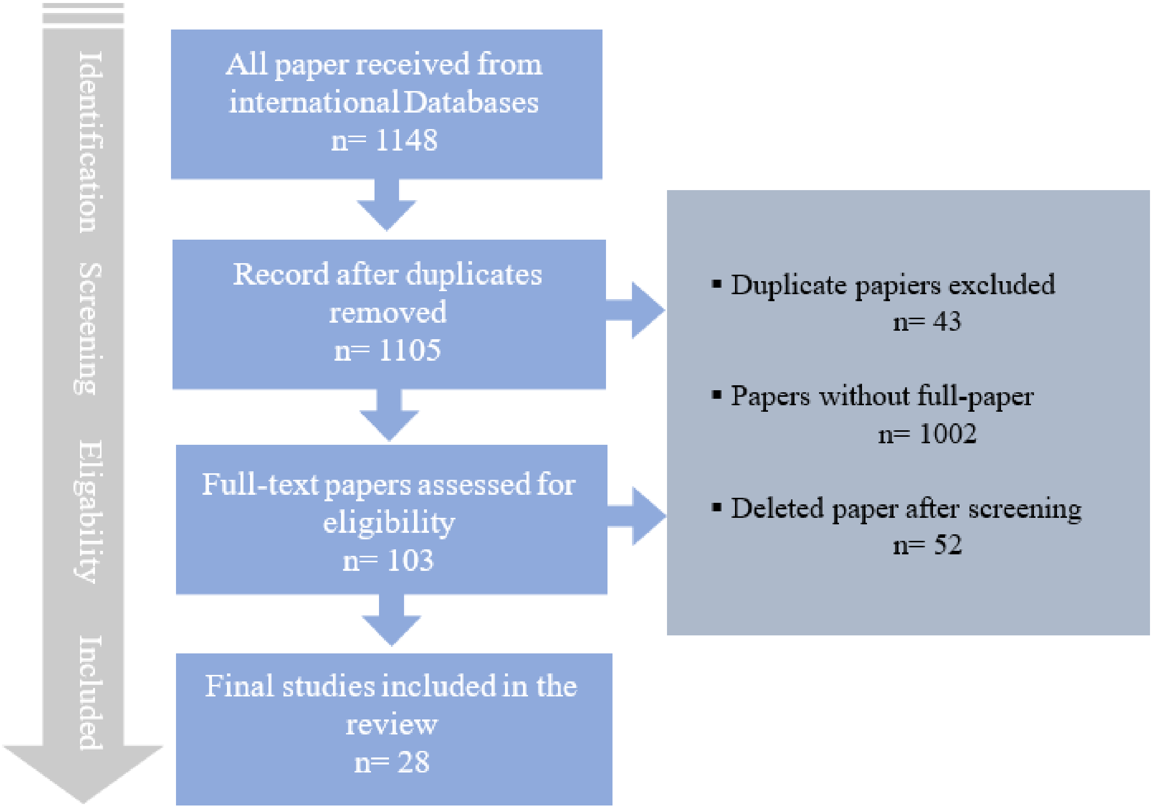

Figure 1. Systematic review flow diagram

3. Systematicreview of mathematical and statistical modeling of industrial accident consequences in Algeria

Algeria's major industrial sectors include hydrocarbons, petrochemicals, electrical, food processing, and manufacturing[25]. The hydrocarbon sector is the largest industrial sector in the country, accounting for 19% of GDP, 93% of product exports, and 38% of budget revenues between 2016 and 2021[26, 27]. The manufacturing sector has also seen growth[28], with a 59.21% increase in manufacturing output from 2020 to 2021, reaching $43.40 billion.

The Algerian government has been focusing on increasing the role of industry in the economy[29], and the manufacturing sector's economic contribution has reached 5.6% of the total Gross Domestic Product (GDP). Heavy industrial activity is growing rapidly in the country, with plans for large-scale expansion in several segments, such as steel and construction materials[25]. Manufacturing industries, including automotive and electronic goods assembly, are also expected to see spurred growth, but their success will depend on how quickly they can build effective and profitable integration rates and generate economies of scale.

3.1. Historical context of industrial accidents in Algeria

In recent years, Algeria has faced challenges related to industrial accidents, particularly in the hydrocarbons sector[30].Human factors have been identified as the main cause of most accidents due to non-respect of safety procedures and lack of concentration of workers[31]. The Algerian government and local companies have been working to address these issues and improve safety standards in the industry.

Industrial accidents, characterized by unexpected events that disrupt the normal course of industrial operations, have the potential to result in catastrophic consequences. These consequences encompass a wide range of effects, from immediate injuries and fatalities to long-term environmental and socio-economic impacts [32, 33]. Algeria, with its burgeoning industrial sector, is not immune to the risks associated with industrial accidents. As the country continues to experience industrial growth, the potential for accidents and their subsequent consequences becomes a matter of paramount concern.

The problem at hand can be summarized as follows: Despite the increasing recognition of the significance of industrial accident consequences modeling in enhancing safety measures and disaster management, there exists a paucity of comprehensive studies that focus specifically on Algeria. The Algerian industrial landscape, marked by sectors such as oil and gas, petrochemicals, mining, and manufacturing, presents unique challenges and vulnerabilities that necessitate tailored approaches for assessing and mitigating accident consequences.

This research gap becomes particularly pronounced when considering the period between 2003 and 2023, a timeframe during which Algeria witnessed substantial industrial development and expansion[34]. Industrial accidents during this period,such as the two accidents that occurred in the Skikda refinery in 2004 and 2005,have highlighted the need for a localized and comprehensive understanding of accident consequences, as the impact of these events extends far beyond immediate human and structural damage [35].

The absence of an exhaustive review of the literature pertaining to industrial accident consequences modeling in Algeria between 2003 and 2023 hampers the country's ability to:

- Develop and implement effective safety protocols that are contextually relevant to the Algerian industrial sector.
- Enhance disaster preparedness and response strategies by drawing from lessons learned from past incidents.
- Foster a culture of safety and risk awareness among industrial stakeholders.

To address these critical concerns, it is imperative to synthesize and analyze existing research and modeling efforts related to industrial accident consequences in Algeria. By doing so, this study seeks to provide a comprehensive overview of the state-of-the-art, identify gaps in knowledge, and offer recommendations for future research and policy development in the realm of industrial safety and accident management within the Algerian context.

In the subsequent sections of this paper, we will delve into the methodologies employed in previous studies, examine key findings and trends, and propose areas where further research can contribute to mitigating the consequences of industrial accidents in Algeria.

3.2. Key Concepts and Theories in modelingindustrial accident consequences

Industrial accidents have significant consequences in various aspects. They negatively affect job opportunities and workers' earnings, leading to lower employment probabilities and delayed wage penalties, especially in regions with higher unemployment rates [36]. Major process accidents can result in harm to workers and the public, loss of company property, business interruption, and environmental degradation[37]. Here are some common consequences of industrial accidents[38-40]:

- Injuries and Fatalities: Industrial accidents can result in injuries to workers or even fatalities. These injuries can vary from minor cuts and bruises to severe burns, amputations, or life-threatening conditions;
- Property Damage: Accidents in industrial settings can lead to damage to equipment, machinery, and infrastructure, resulting in financial losses for the company;
- Environmental Damage: Some industrial accidents can lead to the release of hazardous substances or pollutants into the environment, causing harm to ecosystems, water sources, and air quality;
- Production Downtime: Accidents can disrupt production processes, leading to downtime and decreased

productivity. This can result in financial losses for the company due to reduced output and potential contractual penalties;

- Reputation Damage: High-profile industrial accidents can harm a company's reputation, leading to a loss of customer trust and confidence, which can have long-term financial implications;
- Legal and Regulatory Consequences: Companies may face legal action, fines, or penalties if they are found to be negligent in preventing industrial accidents. Regulatory agencies may also impose stricter safety requirements;
- Psychological Impact: Workers who witness or are involved in industrial accidents may suffer from psychological trauma, including post-traumatic stress disorder (PTSD) or anxiety;
- Insurance Costs: After an accident, insurance premiums may increase, placing a financial burden on the company;
- Worker Morale: Industrial accidents can lower morale among workers, leading to decreased job satisfaction and potentially higher turnover rates;
- Supply Chain Disruptions: Accidents in one part of the supply chain can disrupt the entire production and distribution process, affecting not only the company but also its suppliers and customers.

To mitigate these consequences, industries often prioritize safety measures, risk assessments, employee training, and emergency response plans[41]. Industrial accident modeling and analysis can help identify potential hazards, assess the likelihood of accidents, and develop strategies to minimize their impact.

Industrial accident consequence modeling involves the use of various tools to evaluate the potential outcomes of accidents in industrial settings, such as the dispersion of toxic gases, smoke, fires, and explosions[42, 43]. These models help in assessing the impacts of accidents, including factors like thermal radiation, explosion overpressure, and the dispersion of toxic substances[43]. The development of industrial facilities has led to an increased scale and frequency of accidents, making it crucial to understand and predict their consequences. Analytical models and prediction tools are essential for preventing accidents and improving incident modeling. Consequence modeling is a rigorous and methodical examination of the direct undesirable impacts on the environment and the industrial process, and it plays a vital role in various applications, including the design of new facilities, risk assessment, and emergency planning.

Mathematical modeling and statistical analysis can be used to improve the understanding of industrial accidents. These models help predict ground motion and seismic hazards in the region, which is crucial for assessing the risk of earthquakes and designing structures accordingly [29]. Furthermore, mathematical and statistical models can be used to simulate the propagation of toxic and flammable gas clouds during industrial accidents, allowing for the estimation of the number of injured people and the identification of thermal hazard zones[44, 45]. By utilizing mathematical modeling and statistical analysis, researchers can gain a better understanding of the causes and consequences of industrial accidents[46], leading to the development of effective preventive measures and safety regulations.

These models help in predicting the nature and extent of damages caused by accidents without imposing unrealistic simplifications or restrictions [47]. Some of the commonly used models include logistic regression, decision trees, neural networks, support vector machines, naive Bayes classifiers, and random forests [48]. These models are applied to forecast the occurrence of human, environmental, and material consequences of industrial accidents based on available data [49]. Additionally, new accident models based on systems theory, such as the Systems-Theoretic Accident Model and Processes (STAMP), Functional Resonance Accident Model (FRAM), and AcciMap methods, have been introduced to overcome limitations in identifying causes of accidents in modern industries [50]. These models provide a systemic approach to understanding accidents in complex socio-technical environments[51].

In the following table (Table 1), we present an overview of the key characteristics, advantages, and limitations of each modeling technique when applied to the analysis of industrial accident consequences[51].

Table 1. Modeling accidents techniques

Mathematical and Probabilistic Models	**Input Values**	**Results**	**Advantages**	**Limitations**
Poisson Regression Negative Binomial Regression	Historical accident data, time, location, and contributing factors.	Estimated accident frequencies and probabilities.	Simple to implement, useful for predicting the likelihood of accidents	Assumes accidents following a random process may not capture complex dependencies.
Event Tree Analysis	Sequence of events, probabilities of each event.	Identification of combinations leading to the undesired event.	Identifies root causes of accidents, visual representation	Requires detailed event data may not account for complex interactions.
Fault Tree Analysis	Undesired event, component failure probabilities.	Probabilities of specific accident scenarios.	Visual representation of accident sequences, quantifies probabilities	Complex large systems require data on component failure probabilities.
System Dynamics Models	Equations, parameters, initial conditions.	Time-dependent behavior of variables.	Captures dynamic interactions and allows scenario testing.	Complex to develop, data-intensive, and requires calibration.
Agent-Based Models	Agent behaviors, system rules, and initial conditions.	Simulated behavior of individual agents in accident scenarios.	Captures individual-level interactions, useful for studying human behavior.	Complex to develop, data-intensive, and computationallydemanding.
Statistical Regression Models	Accident data, independent variables (e.g., time, safety measures).	Regression coefficients, relationships between variables.	Quantifying relationships is interpretable and useful for predictive modeling.	Assumes linear relationships may not capture complex interactions.
Monte Carlo Simulation	Probability distributions of input parameters.	Probability distributions of accident consequences.	Accounts for uncertainty and variability, versatile.	Computationally intensive, it requires input parameter distributions.
Bayesian Networks	Causal relationships,	Probabilistic assessments of	Models complex dependencies	Requires expert knowledge of construction, data-

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	conditional probabilities.	accident scenarios.	uncertainty handling.	intensive.
Data Envelopment Analysis (DEA)	Efficiency measures of different facilities safety indicators.	Relative efficiency scores of facilities.	Benchmarking identifies best practices.	Assumes that the best-performing facilities are efficient, limited to relative assessments.
Time Series Analysis	Accident data over time.	Trends, patterns, and forecasts.	Identifies temporal patterns, useful for long-term trend analysis.	It may not capture complex causal relationships relying on historical data.

The choice of method depends on the specific characteristics of the accidents, the available data, and the modeling objectives. Often, a combination of these techniques is used to provide a comprehensive understanding of accident consequences and their contributing factors.

3.3. Existing Algerian studies using mathematical and statistical models related to industrial accident consequences

Industrial accident modeling in Algeria is a critical area of study due to the significant number of reported workplace accidents in the country, particularly within the oil and gas industry. According to Zerouki et al. 2023 [52],a total of 42,032 workplace accidents were reported in 2021 by the Algerian National Social Insurance Fund for Salaried Workers in Algeria, of which 38,225 were accidents within the workplace. These accidents pose serious risks to the safety of workers, residents, and the environment, as highlighted by Benaissa et al., 2022 [53]in their study on risk analysis and assessment of a petrochemical plant in Skikda, Algeria.

Mathematical and statistical modeling of industrial accident consequences encompasses a wide range of methodologies, including data envelopment analysis, forecasting, dynamic safety budgeting, and the use of various mathematical models. These approaches provide valuable insights into the factors influencing industrial accidents and contribute to the development of effective accident prevention and management strategies.

To model the effects of Algeria'sindustrial accidents, various mathematical and statistical approaches have been employed in different industriesto analyze the consequences of industrial accidents.In the following section, we will present historicallythe most significant Algerian studies related to mathematical and statistical modeling of the effects of industrial accidents.

This literature review encapsulates a spectrum of studies conducted from 2003 to 2023, focusing on the mathematical and statistical modeling approaches employed to evaluate the ramifications of industrial accidents in various sectors.

The literature review process encompassed a systematic search for pertinent studies across multiple academic databases. Initially, a total of 1,148 search results were obtained and subjected to an initial screening for eligibility. During this initial screening phase, duplicate articles were identified and excluded by thoroughly reviewing the titles and abstracts. Subsequently, a comprehensive examination of the full text of these articles was undertaken, resulting in the final inclusion of 28 studies for comprehensive analysis.

Noureddine et al. (2003)[54] undertook a radiological contamination assessment following the Algeciras incident, utilizing mathematical modeling to conclude that the investigated area in Algeria remained unaffected by 137Cs releases. Rahmani et al. (2009)[55] ventured into boiler safety with mathematical modeling, emphasizing the pivotal role of control systems in averting accident repercussions.Hamzi &Innal (2011) [56] propose a quantitative risk assessment approach to evaluate the frequency and measurable consequences of accidents, particularly in fire-related scenarios. In the context of petrochemical plants, Ouddai et al. (2012)[57] conducted a qualitative assessment of the causes and aftermath of the Skikda LNG accident, highlighting communication and maintenance as key factors. Fire safety came under scrutiny by Chettouh et al. (2014a)[58], who employed mathematical modeling to analyze uncertainties in NO_2 dispersion from crude oil tank fires, underscoring the importance of precision in modelling;moreover, Chettouh et al. (2014b)[59] explored the integration of uncertainty theory into the Dynamic LCA-Fire methodology to assess fire effects, expanding the scope of life cycle impact assessment.Innal et al. (2014)[60] introduced a Petri Net-based approach to modeling and evaluating emergency plans, with a specific focus on the scenario of a condensate storage tank fire. The research takes into consideration uncertainties related to task execution durations and the reliability characteristics of technical equipment within emergency plans. Given the inherent complexity and uncertainty in emergency plans, the study utilizes Monte Carlo simulation to obtain results.Cement plant safety culture was explored by Chaib et al. (2015)[61], emphasizing its significance in enhancing working conditions and accident prevention. A broader timespan was examined by Samia Chettouh et al. (2016)[35], who statistically analyzed accidents in the Skikda Oil Refinery, accentuating the need for robust safety measures. Boiler safety was revisited by Cheridi et al. (2016)[62] using mathematical modeling, highlighting control system efficacy in accident mitigation.Aissani et al. (2018)[63] introduced Bayesian risk assessment in cement manufacturing, identifying major hazards and recommending preventive measures. Chettouh et al. (2018)[30]combined statistical analysis with hazard assessment software (ALOHA) using lessons learned from oil refining accidents in Algeria to contribute to modeling the effects of accidents in refining activities. This approach aligns with the need for comprehensive risk assessment methodologies, as suggested by (Zerrouki, 2023)[52], who presented a risk assessment methodology for a liquefied natural gas process facility in west Algeria.

Sellami et al. (2018a)[64] introduced Computational Fluid Dynamics (CFD) modeling for predicting Boiling Liquid Expanding Vapor Explosion (BLEVE) thermal effects, thus enhancing the precision of Quantitative Risk Analysis (QRA) outcomes. Building on this foundation, Sellami et al. (2018b) [65]proposed a mathematical model rooted in the Sedov-Taylor blast wave solution. This innovative approach addressed the limitations associated with empirical correlations and underscored the importance of precision in risk assessment. Furthermore, Sellami et al. (2018c)[66] seamlessly integrated the Sedov-Taylor model into QRA, demonstrating its significant relevance in the context of consequence analysis.

Bekhouche et al. (2019)[67] employed tools like HAZID and PHAST to enhance safety measures in liquefied natural gas (LNG) units. Hadef et al. (2020)[68] stressed the importance of fire and explosion risk assessment in evolving energy sources, specifically hydrogen production. Bouafia et Al. (2020)[69] conducted a quantitative risk assessment for a major gasoline release in a petrochemical plant, utilizing HAZOP, bow tie, and simulation with PHAST to identify affected areas and assess risk consequences. Hellas et al. (2021)[70]analyzed potential accident scenarios related to gas leakage and tank rupture, emphasizing the influence of atmospheric conditions on dispersion scenarios. Lastly, Aila et al. (2021)[71]conducted a quantitative assessment of risks associated with LPG storage and distribution stations, focusing on modeling various accidental sequences and their consequences, including vapor cloud explosions, pool fires, and toxic cloud dispersion.

Boudiaf et al. (2021)[69] addressed the risk management requirements within the hydrocarbon industry. They introduced accident scenario modeling through ALOHA software and conducted hazard identification using XRISK software. Similarly, Taibi et al. (2023)[72] performed an industrial risk assessment around a pentane storage tank in Hassi R'MelCity, Algeria. They utilized ALOHA software to simulate the potential extent of pollution resulting from a pentane leakage, emphasizing the associated environmental risks.

Chebila (2021)[47]explored machine-learning techniques to predict the consequences of industrial accidents involving dangerous substances, highlighting the efficacy of random forests and neural networks.Hadef et al. (2022)[73] delved into domino effect analysis, employing the MICDE method to assess the impacts of BLEVE phenomena at an LPG storage facility.Djaballah et al. (2023)[74] investigated occupational diseases and accidents at a glass manufacturing plant, aiming to enhance occupational safety practices. Heddar et al. (2023)[75] introduced the MASOCU-DBD method for analyzing driver behavioral deviations leading to road crashes at work. Sardou et al. (2023)[76] developed mortality indices to understand flood fatalities in western Algeria and southern Italy. Taibi et al. (2023)[72] employed ALOHA software to assess the extent of pollution in Hassi R'MelCity due to LPG storage sphere leakage. Bendib et al. (2023) [77]presented a risk assessment methodology for LPG storage at the SKIKDA refinery, integrating D-HIGRAPH, HAZOP, and ALOHA software for comprehensive analysis.

4. Results and discussions

4.1. Summary of Studies Related to Mathematical and Statistical Modeling of Consequences from Industrial Accidents in Algeria

Table 2 provides an overview of key studies related to mathematical and statistical modelingof accident consequences in various industrial sectors. It summarizes essential elements such as the study titles, authors, publication years, sectors of activity, types of models employed, methodologies utilized, variables considered, software tools used, resulting insights, and identified limitations. These studies address a range of topics, including quantitative risk assessment for environmental impacts of fires in refineries, the evaluation of emergency plans with a focus on uncertainty, and safety risk analysis concerning major gasoline releases in petrochemical plants. Each study contributes valuable insights and approaches to enhance safety and risk management within their respective domains, offering a comprehensive overview of relevant research in this field.

Table 2. Summary of studies

Title of the study	**Authors**	**Tear**	**Sector**	**Model**	**Method**	**Variables**	**Software**	**Finding**	**Limitations**
Evaluation of the radiological situation in Algeria after the Algeciras incident	Noureddine et al.	2003	Steel Manufacturing	Mathematical model	In situ gamma radiation measurements, sample collection, gamma spectrometry, radiochemical analysis	137Cs contamination in air, soil, sediment, vegetation, seawater	Not specified	No increase in 137Cs levels from the Acerinox factory in Algeciras	Not specified
Assessment of boiler tubes overheating mechanisms during a postulated loss of feedwater accident	Rahmani et al.	2009	Industrial Boiler	Mathematical model	Use of RELAP5/Mod3.2 system code for simulation	Thermal-hydraulic behavior during loss of feedwater accident	RELAP5/Mod3.2	Successful use of RELAP5 for boiler system simulation and efficiency of control systems	Limited to a specific boiler system; Simplified assumptions in some models
A quantitative risk assessment approach for the dynamic environmental impact of fire	Hamzi et al.	2011	Refinery	Mathematical & Statistical model	Quantitative riskassessmentapproach	Accident frequency, measurable consequences	Not specified	Assessment of accident frequency and measurable consequences, focus on fire risk in a refinery, proposed safety measures.	Specific to fire risk in a refinery, it does not explore alternative modeling approaches.
The Skikda LNG accident: Losses, lessons learned and safety climate assessment	Ouddai et al.	2012	Petrochemical Plant	Statistical model	Analysis of causes and consequences, safety climate assessment	Causes of the Skikda LNG accident, safety climate assessment	Not specified	Poor maintenance, unit distribution, and safety communication identified; Divergence in safety perceptions	Specific to the Skikda LNG accident, Limited scope to one incident
Industrial fire simulation and uncertainty associated with the	Chettouh et al.	2014	Refinery	Statistical model	Uncertainty analysis using a Monte Carlo approach	NO_2 atmospheric dispersion from a crude oil tank	Monte Carlo approach	Uncertainty analysis showed significant parameters	Limited to a specific type of industrial fire

Emission Dispersion Model						fire		affecting NO_2 dispersion; Wind speed and viscosity were significant.	accident; Results specific to NO_2 dispersion.
Interest of the theory of uncertain in the Dynamic LCAFire methodology to assess fire effects	Chettouh et al.	2014	Refinery	Mathematical model	Dynamic LCA-Fire methodology combining LCA-Fire and Dispersion Numerical Model	Fire effects in the petroleum production process	Not specified	Methodology for assessing fire effects proposed; Applicability to petroleum production demonstrated.	Specific to petroleum production; Limited to methodology presentation
Handling uncertainty in emergency plan evaluationusing generalized Petri Nets: Case study: Loss of a condensate tank containment	Innal et al.	2014	No specified	Mathematical & Statistical model	Petri Net-based approach, Monte Carlo simulation	Task execution durations, technical equipment reliability	Not specified	Model and evaluation of emergency plan performance, consideration of uncertainty factors in plan execution	Specific to emergency plan evaluation, focus on a particular method (Petri Nets), complexity of emergency plans not thoroughly addressed
Preserving and improving the safety and health at work: Case of Hamma Bouziane cement plant (Algeria)	Chaib et al.	2015	Cement Manufacturing	Statistical model	Safety culture analysis	Safety culture in cement plants	Not specified	Emphasizes the importance of safety culture; Calls for continuous improvement	Limited to the case study of a cement plant; Focus on safety culture.
Examination of fire and related accidents in Skikda Oil Refinery for the period 2002-2013	Chettouh et al.	2016	Petrochemical Plant	Statistical model	Statistical analysis of accidents and incidents	Frequency and causes of fire, explosion, and toxic gas releases in the Skikda Oil	Not specified	Fire most frequent accident; NO2 toxic effects unacceptable; Suggested relocation in case of	Limited to Skikda Oil Refinery; Focus on accident frequency.

						Refinery		similar accidents	
Numerical simulation of a 374tons/h water-tube steam boiler following a feedwater line break	Cheridi et al.	2016	Industrial Boiler	Mathematical model	Simulation using RELAP5 system code	Behavior of a water-tube steam boiler during a feedwater line break accident	RELAP5 system code	Successful simulation of boiler behavior during accident; Control system mitigated accident consequences	Limited to a specific boiler system; Specific to feedwater line break
Decision process for safety based on the Bayesian approach	Aissani	2018	Cement Manufacturing	Statistical model	Bayesian approach to risk assessment	Risk assessment based on accident data	Not specified	Bayesian approach for risk assessment: Identified major hazards and preventive measures	Limited to one cement factory; Focus on Bayesian approach
Contribution of the lessons learned from oil refining accidents to the industrial risks assessment	Chettouh et al.	2018	Petrochemical Plant	Statistical model	Statistical analysis combined with hazard assessment software	Causes and effects of accidents in the oil refining sector in Algeria	Hazard assessment software (not specified)	Identification of frequent accidents and unacceptable NO2 levels; Limitation to Skikda refinery data	Limited to accidents in the Skikda refinery, Specific to one sector
BLEVE fireball modeling using Fire Dynamics Simulator (FDS) in an Algerian gas industry	Sellami et al.	2018	Gas Processing Industry	Mathematical model	CFD using FDS	BLEVE thermal effects	FDS	CFD methodology predicts BLEVE thermal effects with good agreement compared to experiments.	Limited to BLEVE thermal effects; Specific to gas industry; Sensitivity analysis required for parameter selection.
Quantitative consequence analysis using Sedov-Taylor blast wave model. Part I:	Sellami et al.	2018	Gas Processing Industry	Mathematical model	Analytical model based on Sedov-Taylor solution	BLEVE overpressure effects	Analytical model	The analytical model estimates BLEVE overpressure effects with good	Limited to BLEVE overpressure effects; Focuses on gas processing

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Model description and validation								precision compared to experiments.	industry.
Quantitative consequence analysis using Sedov-Taylor blast wave model. Part II: A case study in an Algerian gas industry	Sellami et al.	2018	Gas Processing Industry	Mathematical model	Integration of the Sedov-Taylor model into QRA	BLEVE blast effects	Quantitative Risk Analysis (QRA) software	Sedov-Taylor model integrated into QRA for BLEVE blast effect assessment; Improved risk assessment.	Limited to BLEVE blast effects; Focuses on gas industry.
Fire and Explosion Risks in Petrochemical Plant: Assessment, Modeling and Consequences Analysis	Bekhouche et al.	2019	Oil and Gas Industry	Mathematical&Statistical model	Hazard identification using HAZID	Fire and explosion risks in LNG unit	DOW's F&EI, PHAST	Hazard identification and modeling of fire and explosion risks; Suggested preventive measures.	Limited to fire and explosion risks in LNG units, Specific to oil and gas industry.
Preliminary hazard identification for risk assessment on a complex system for hydrogen production	Hadef et al.	2020	Hydrogen Production	Mathematical&Statistical model	FAST and HAZOP analysis	Risk scenarios and consequences	Not specified	Evaluation of risk scenarios in hydrogen production system; Identification of major risks.	Limited to hydrogen production, Specific to risk analysis in the hydrogen domain.
Safety Risk Analysis and Accidents Modeling of a Major Gasoline Release in Petrochemical Plant	Bouafia et al.	2020	Petrochemical Plant	Mathematical&Statistical model	Qualitative and Quantitative HAZOP, bow tie, Phast simulation, societalriskcurves FN	Sources of accidental gasoline release, affected areas, risk consequences, frequency of occurrence, fatalities	PHAST	Analysis of risk and accidents related to gasoline release, identification of sources and affected areas, simulation results, safety assessment using FN curves	Focus on gasoline release in a petrochemical plant, specific to this type of accident, limitations not specified.
Modelling of accidental phenomena related to	Hellas et al.	2021	LPG Storage and	Mathematical model	Quantitative risk analysis using PHAST	LPG leakage and rupture	PHAST	Modeling potential accident scenarios	Focuses on LPG fuel; Limited to

leakage and tank rupture of a vehicle converted to LPG			Distribution			scenarios		related to LPG leakage and tank rupture; Sensitivities to climatic conditions.	risk modeling of LPG accidents.
Assessment of an Accidental Liquified Petroleum Gas Release at a Petrochemical Site: a Case Study	Aila et al.	2021	LPG Storage and Distribution	Mathematical model	Quantitative risk assessment with event tree	Hazardous scenarios and consequences	Not specified	Quantitative assessment of risks for LPG storage and distribution stations; Identification of high-risk scenarios.	Focuses on LPG storage and distribution, Specificallyon risk assessment of LPG accidents.
Assessment of potential dangers of installations at Rhourde Nouss station within the framework of law 45/DG (Ouargla, Algeria)	Boudiaf et al.	2021	Oil and Gas Industry	Mathematical&Statistical model	Mathematical	Accident scenarios, hazards	ALOHA, XRISK, LOPA	Identification of hazards, recommendations for accident prevention	Limited to hazard modeling, Specific to the oil and gas sector.
Predicting the consequences of accidents involving dangerous substances using machine learning	Chebila	2021	No specified	Statistical model	Statistical	Consequences of industrial accidents	Various machine-learning tools	Distinctive ability of random forests and neural networks to predict consequences of accidents	Relies on the availability of representative data.
Domino effect analysis at a gas facility: Application at a storage facility	Hadef et al.	2022	Gas Processing Industry	Mathematical model	Domino effect analysis using the MICDE method	Domino effects due to the BLEVE phenomenon	MICDE method	Identification of potential domino effects due to BLEVE; Affected equipment in the vicinity	Focuses on domino effects, Specific to gas storage.
Assessment and Analysis of Occupational Diseases	Djaballah et al.	2023	Glass Industry	Statistical model	Survey with open-ended questions	Occupational diseases,	Survey data analysis	Recommendations for enhancing	Based on survey data Specific to

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and Accidents in Chlef Glassworks (NOVER)- Algeria						accidents		occupational safety practices	the glass industry.
Contribution to the analysis of driver behavioral deviations leading to road crashes at work	Heddar et al.	2023	No specified	Mathematical model	MASOCU-DBD method (BM-NSA model, AHP, CBA)	Driver behavioral deviations	Multi-criteria analysis and mathematical modeling	Analysis of driver behavioral deviations	Focuses on road crashes at work; Relies on data and modeling.
Assessment of flood mortality indices in a Mediterranean framework: A comparative analysis between western Algeria and southern Italy	Sardou et al.	2023	No specified	Statistical model	Development of mortality indices	Flood mortality indices	Comparative analysis of flood mortality in different regions	Focuses on flood mortality; Comparative analysis.	Not specified
Examining the potential of damage in threat zones around the LPG storage sphere in Hassi R'MelCity, Algeria	Taibi et al.	2023	LPG Storage and Distribution	Mathematical model	Hazard modeling using ALOHA	Thermal effects of BLEVE	ALOHA	Identification of threat zones due to BLEVE thermal effects	Focuses on threat zones; Specific to LPG storage.
A systematic approach for risk assessment in LPG storage tanks area – SKIKDA refinery	Bendib et al.	2023	LPG Storage and Distribution	Mathematical model	Risk assessment using D-HIGRAPH, HAZOP, and ALOHA	Risk assessment, explosion effects	D-HIGRAPH, HAZOP, ALOHA	Risk assessment methodology for LPG storage area; Simulation of explosion effect	Specific to LPG storage area; Incorporates various methodologies.

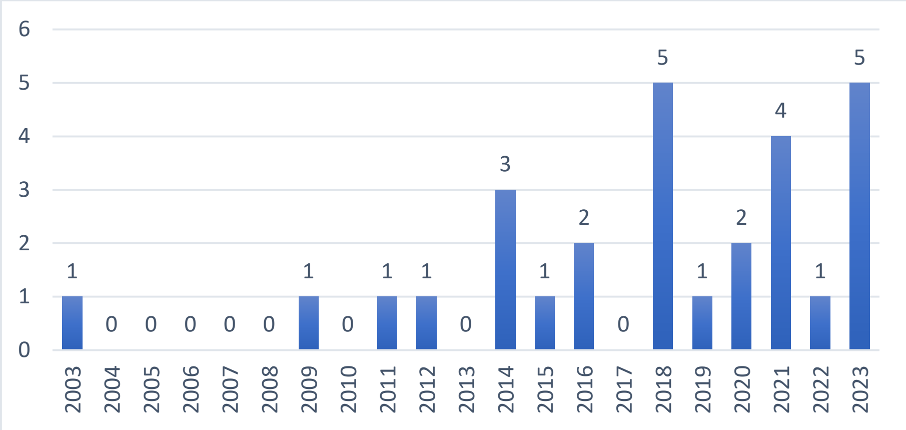

Figure 2. Frequency ofAlgerian industrial accident modeling studies for the period 2003 to 2023

Fig. 2 presents the frequency of Algerian industrial accident modeling studies for the period 2003 to 2023. In analyzing this trend, one could infer that industrial accident modeling has gained more attention in recent years, perhaps due to an increase in industrial activity, regulatory changes, or heightened awareness of the importance of workplace safety. The gaps in earlier years might indicate a lack of data collection, reporting mechanisms, or possibly lower prioritization of such studies during those periods.

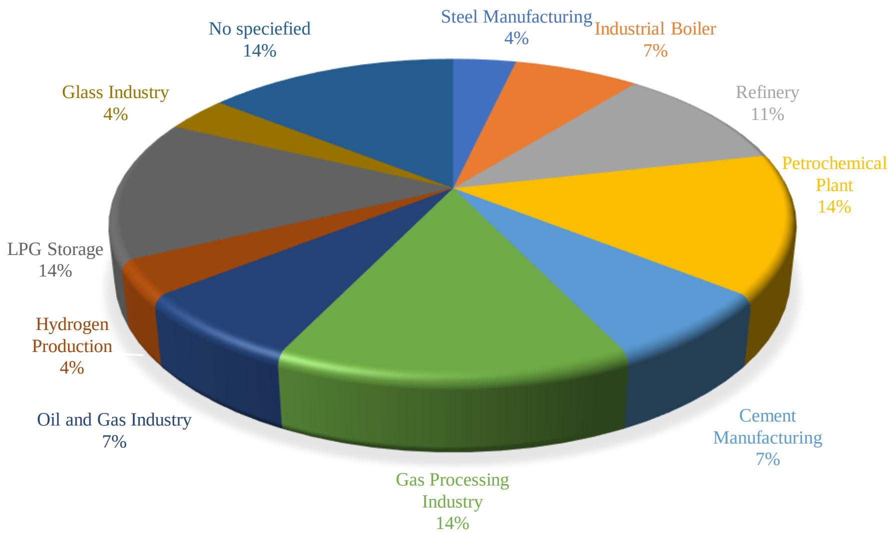

Figure 3. Distribution of studies according to activity sector

Fig.3 displays the distribution of studies according to the activity sector related to industrial accident modeling in Algeria. This distribution suggests that the focus of industrial accident modeling studies is relatively spread across several sectors, with the highest concentration in the petrochemical, gas processing, and LPG storage sectors. Each of these sectors has a significant share of studies, which may indicate their critical importance in the context of industrial safety in Algeria. The fact that 14% of studies are not specified to any sector could suggest either a broader approach in those studies or a lack of detailed reporting. The pie chart can be interpreted to reflect areas of industrial activity that are potentially more prone to accidents or where the consequences of accidents could be more severe, hence the need for more intensive study. The focus on petrochemical plants, gas processing, and LPG storage aligns with global trends where these sectors are considered high-risk due to the hazardous materials handled and the processes involved.

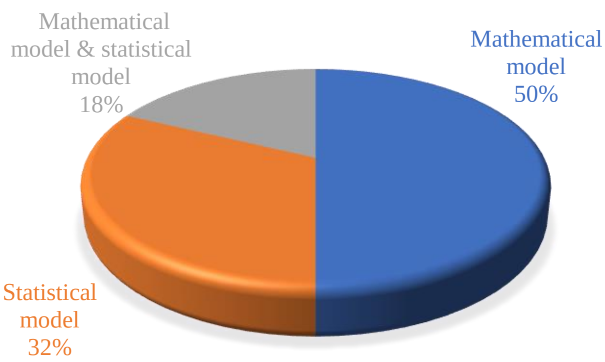

Figure 4. Distribution of studies according to the type of used model

The pie chart in Fig.4 illustrates the distribution of studies on industrial accident modeling in Algeria according to the type of model used. Mathematical models are the most used in the studies, comprising half of the approaches, indicating a preference for models that are based on theoretical frameworks or deterministic processes in industrial accident modeling. Statistical models are also significant, making up nearly one-third of the studies. This suggests that empirical analysis of data and probabilistic methods are also important in understanding and predicting industrial accidents. 18 % of studies combined both mathematical and statistical models, which could represent a comprehensive approach, taking advantage of both theoretical and empirical insights.

The preference for mathematical models may reflect the nature of industrial processes, where controlled conditions and known physical laws can often predict outcomes reliably. However, the substantial use of statistical models underscores the importance of analyzing historical data to understand accident trends and the stochastic nature of accidents. Several studies utilized mathematical models to simulate industrial accident scenarios, including the behavior of systems during accidents. Examples include the use of mathematical models in assessing radiological contamination, boiler tube overheating mechanisms, water-tube steam boiler behavior, and more.

Statistical models are usually dependent on the quality and quantity of data available, which can sometimes be a challenge in industrial settings due to underreporting, incomplete data, or the rarity of accidents. Statistical approaches wereemployed, focusing on data analysis, accident frequency, and consequences assessment. Studies utilized statistical methods to analyze accidents, incidents, and safety climate assessments in various industrial sectors.

Combining both mathematical and statistical models can potentially lead to a more robust and nuanced understanding of industrial accidents, allowing for better risk assessment and preventive measures.Some studies combined both mathematical and statistical modeling approaches to assess industrial accident risks and consequences comprehensively. This integration allowed for a holistic view of risk assessment and safety analysis.

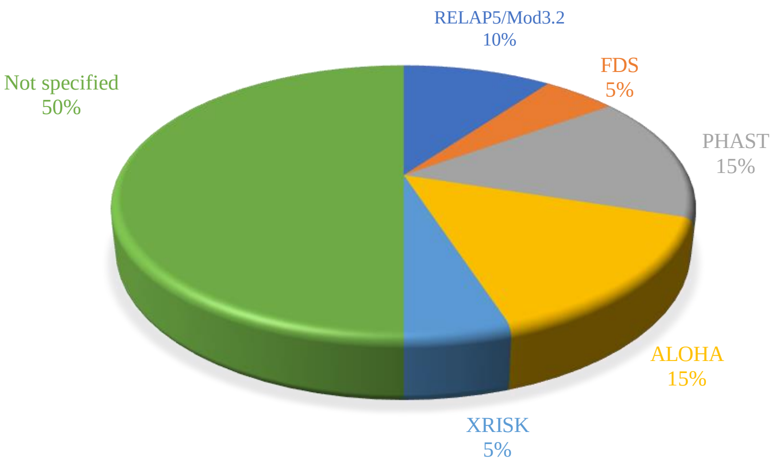

Figure 5. Distribution of studies according to the used software.

Fig. 5presentsthe software tools used in the studies on industrial accident modeling in Algeria. A large part of the studies (50%) does not specify the software used. This could be due to proprietary tools, the use of in-house developed software, or a lack of standardization in reporting.It may also reflect a gap in the documentation of methodologies, which could be a barrier to replicating studies and comparing results across different research.

PHAST (Process Hazard Analysis Software Tool) and ALOHA (Areal Locations of Hazardous Atmospheres) are both used in 15% of the studies, indicating a focus on chemical release and dispersion modeling, which is important for understanding the impact of hazardous material accidents.The use of recognized software tools like PHAST and ALOHA indicates alignment with international standards and practices for hazard analysis.

RELAP5/Mod3.2 is used for thermal-hydraulic simulation, suggesting some studies are focusing on accident scenarios that involve fluid flow and heat transfer, which are critical in nuclear and process industries.The presence of specialized tools like RELAP5 suggests that some industries in Algeria may be operating with complex systems that require advanced simulation capabilities.

FDS and XRISK have smaller shares, but their presence indicates that fire dynamics and risk assessment are also areas of concern within the scope of industrial accident modeling.

The variety of tools reflects the diverse nature of industrial accidents and the need for different types of analysis, from dispersion modeling to fire dynamics and risk assessment.

Several methods were employed, as shown in Table 2. These methods are qualitative (expert opinion, text reviews, and industry expert opinions) and quantitative (risk assessment methods, HAZOP, Bowtie, FTA, ETA, and HAZID).As a result, numerous scenarios, including fire, explosion (BLEVE, UVCE), and hazardous substance release, were evaluated. The combined use of two or more methods and software tools, including HAZOP, bow tie, PHAST, and ALOHA simulation, has also been identified.

4.2. Key Findings and Trends

The synthesis of findings from the reviewed literature reveals several key results and trends:

- Identification of Hazards: The studies consistently identify specific hazards and accident scenarios within various industrial sectors in Algeria. These findings contribute to a better understanding of potential risks and their implications;
- Safety Culture Analysis: Some studies emphasize the importance of safety culture analysis in accident prevention and mitigation, particularly in sectors like cement manufacturing. These analyses highlight the role of organizational culture in promoting safety;

- Simulation and Software Use: Advanced simulation software and modeling tools, such as RELAP5, PHAST, and ALOHA, are frequently employed to enhance the precision of accident consequence predictions. These tools facilitate the simulation of various accident scenarios, aiding decision-makers and safety professionals;
- Recommendations: Many studies provide recommendations for safety improvements and preventive measures based on their findings. These recommendations are aimed at reducing the likelihood and severity of industrial accidents;
- Specific Incident Analysis: A subset of studies focuses on specific industrial incidents, such as the Skikda LNG accident, offering in-depth analyses of their causes, consequences, and lessons learned. These analyses contribute to a better understanding of the unique challenges associated with these incidents;
- Risk Assessment: The quantification of risk, including the assessment of high-risk scenarios and their potential consequences, is a recurring theme in many studies. This facilitates prioritizing safety measures and risk reduction strategies;
- Limitations and Data Availability: It is essential to acknowledge the limitations of the existing studies, which often include constraints related to data availability, the specificity of models, and the focus on particular industrial sectors or incidents.

4.3. Gaps in the literature and areas for future research

Despite valuable contributions, the reviewed studies exhibit certain limitations, including data availability and model validation challenges. Future research should prioritize data collection and validation efforts to enhance the accuracy and reliability of models. Additionally, studies that consider the impact of climate change and evolving industry practices on industrial risks are warranted.

The present systematic review of the mathematical and statistical modeling of industrial accidents in Algeria highlights several critical research gaps.

First and foremost, there is a pressing need for a comprehensive, cross-sectoral analysis that integrates various modeling approaches into a unified framework for assessing industrial accident consequences in Algeria. While individual studies have provided valuable insights into specific sectors and accident types, a holistic approach that considers the diverse industrial landscape of Algeria is lacking. This gap hinders the development of a comprehensive understanding of industrial accident dynamics in the country.

Secondly, there is a potential gap in the utilization of advanced modeling techniques and data analytics, such as machine learning, to enhance the predictive accuracy and real-time monitoring of industrial accident consequences. The integration of these cutting-edge approaches remains underexplored in the Algerian context, limiting the potential for more effective safety measures and risk management strategies across industries.

Lastly, a critical research gap exists in the absence of a comprehensive and up-to-date framework that consolidates various modeling approaches and addresses emerging challenges in the field. To bridge this gap, a comprehensive comparative study is required to assess the suitability and effectiveness of different risk assessment methodologies and tools within the Algerian industrial setting. Such a study would provide invaluable insights for improved safety management practices and policy recommendations tailored to the specific needs and constraints of the region. This research gap represents a crucial avenue for further research in the domain of industrial accident modeling in Algeria.

5. Conclusion

This systematic review has provided a comprehensive overview of the mathematical and statistical modeling approaches employed in the assessment of industrial accident consequences within the context of Algeria from 2003 to 2023. The analysis of 23 studies across diverse industrial sectors has revealed several key insights and trends.

First and foremost, the reviewed literature underscores the critical importance of mathematical and statistical modeling in enhancing our understanding of industrial accident risks and their potential consequences. Algeria's industrial landscape, including petrochemical plants, refineries, cement manufacturing, and gas processing facilities, has been the focus of intensive research aimed at identifying hazards, assessing risks, and proposing preventive measures.

One of the prominent findings of this systematic review is the significant role of safety culture analysis in accident prevention and mitigation, particularly within sectors such as cement manufacturing. Several studies have highlighted the pivotal importance of fostering a safety-conscious work environment to reduce the likelihood of accidents and improve overall industrial safety.

The integration of mathematical modeling, statistical analysis, and quantitative risk assessment methods has allowed for a holistic evaluation of industrial accident scenarios. This approach has facilitated the identification of high-risk scenarios, the prediction of consequences, and the formulation of risk reduction strategies.

Furthermore, the utilization of advanced simulation software and modeling tools, such as RELAP5, PHAST, and ALOHA, has proven invaluable in enhancing the precision and reliability of accident consequence predictions. These tools have enabled researchers to simulate and evaluate various accident scenarios, providing critical insights for decision-makers and safety professionals.

The reviewed literature indicates that Algeria has made commendable progress in the field of industrial accident modeling, contributing valuable knowledge to improve safety practices and reduce the environmental and societal impacts of accidents. However, it is essential to acknowledge the limitations of the existing studies, including data availability constraints and the specific focus on certain industries or incidents. The systematic review reveals certain gaps and opportunities for future research. Many studies are limited in their scope, focusing on specific incidents or sectors, indicating a need for more generalized models applicable across various industries. Additionally, while the field has made strides in modeling and risk assessment, there's room for further exploration in predictive modeling, particularly using advanced techniques like machine learning. Long-term impact analysis of industrial accidents, encompassing environmental, health, and socio-economic factors, is another area that warrants more attention.

This systematic review serves as a valuable resource for researchers, policymakers, and practitioners seeking to gain insights into the modeling and assessment of industrial accident consequences in Algeria. It offers a roadmap for future research endeavors in this critical area of study.

Future research should aim for more integrative modeling approaches, investigate the impacts of new technologies on industrial safety, and conduct longitudinal studies to understand the long-term consequences of industrial accidents. By addressing these gaps, the field can further strengthen its role in ensuring industrial safety and preventing accidents. Additionally, collaborative efforts among academia, industry, and regulatory bodies should be encouraged further to enhance industrial safety practices in Algeria and beyond. By building on the foundation laid by these studies, Algeria can continue to advance its commitment to industrial safety and accident prevention, ultimately safeguarding both its workers and the environment.

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