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ORIGINAL RESEARCH PAPER

A Multiperspective Model for Environmental Risk Assessment in Oil and Gas Industries

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P A P E R I N F O

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A B S T R A C T

The motivation of this article is the way of ranking hazards through ERA (Environmental Risk Assessment), espacially in O&G industries (Oil & Gas). The paper reviews the related literature, and proposes a flexible ERA model incorporating several risk measures, such as risk impact, risk vulnerabilityt, risk exposure, risk manageability, risk controllability, risk urgency, risk growth, risk probability, risk detection, risk timeframe, risk effect delay, risk awareness, and risk outrage. The model was applied in risk assessment of a storage room of hazardous chemicals in a real-world problem. The results showed that the most important hazard was explosion of the storage. After this major hazard, ranking are explosion, then toxic hazard and leackage.



1. Introduction

Hazard is a phenomenon or an adverse event which has the potential for causing harm/damage to life, property, environment, or any systems [1, 2]. As a defensible trend, risks/hazards can be managed by a process called RMP (Risk Management Process). Several contributors have offered RMP models in the relevant state-of the art [3]. It could be Saied that all of the RMPs have similar framework with minor differences. A typical RMP has five phases. It starts with RMP planning, then risk identification and risk evaluation (or assessment), and finally risk response and risk control [4]. For each phase, there are several tools & techniques to be employed by risk analysts. The current paper concentrates on the third phase, i.e., risk assessment, and aims at developing some supporting tools. On the other hand, risk management is used in several areas, such as project risk management, financial risk management, insurance risk management, business risk management, enterprise risk management, security risk management, health risk management, safety risk management, and environmental risk management. The three last area originates in famous term, HSE (Health, Safety, and Environment). The focus point of this paper, is on the analysis phase of environmental risk management, that is called ERA (Environmental Risk Assessment). Another dimension of risk management refers the application context, for instance, finance and insurance, agriculture, civil & construction, energy, economics, software engineering, etc. The application context that is paid attention by this paper is Oil & Gas industry abbreviated as O &G. Consequently, the current paper is about developing tools for ERA in O &G context.

Environmental risks are those events that can makes negative effects on the natural environment, human health and ecosystems, resulting in long-term damage if not properly controlled. Overall, environmental risks can be mainly categorized into two branches, i.e., “natural hazards” and “anthropogenic hazards”. The former arises from natural phenomena such as hurricanes, earthquakes, flooding, riverine, human pandemic, landslide, widespread hill country, natural electricity failure, wildfire, forest fires, volcanic eruptions, hazardous substances spill, tsunami, coastal flooding/erosion, animal disease, severe wind, drought, telecommunications failure, and landslide. They are not directly caused by human actions, but these activities can intensify these risks. The latter branch involves the hazards caused by human activities, such as industrial pollution, deforestation, chemical use, and climate change.

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The interrelationship between people activities and the environment is a major challenge in the world. This causes ERA studies have become a growing global concern. An ERA is a systematic approach for identifying and evaluating potential environmental risks related to business operations, projects, or events. The ERA goals are to prevent, reduce, or manage adverse impacts on the environment. This ERA process typically includes diagnosing hazards to the environment, and assessing their measures. Anyway, environment risks may have direct/indirect consequences, and is vary depending on the type of activity, geographic location, and value of exposure. ERA and taking productive response actions are essential to address environmental issues and move toward a more stable and sustainable future. There are many reasons to conduct ERA, such as:

- ⊕ Legal compliance (ERA ensures that your firm complies with laws, avoiding penalties),
- ⊕ Environmental protection (ERA plays a vital role in controlling harmful effects of hazards on ecosystems),
- ⊕ Sustainability goals (ERA prevents adverse effects on natural resources),
- ⊕ Financial savings (ERA, without a doubt, prevents considerable financial losses to organizations/countries caused by environmental incidents or resource depletion),
- ⊕ Stakeholders trust (ERA sends the organization's commitment to environmental accountability, resulting in enhancement of your reputation for stakeholders), and
- ⊕ Reputational considerations (the overall outputs of ERA is preventing reputational damage for your system).

The article is structured as follows. Section 2 contains a brief literature review on the application of ERA in O&G. The research gap is described in section 3. Sections 4 and 5 are cores of this paper. They include the employed methodology, and research findings by the paper. After that, a validation of the proposed model is explained in section 6. The respected reader can find a study case in the next section. Finally, section 8 summarizes the paper, and points out future research areas.

2. Literature Review

The focus point of this paper is on the tools and techniques for ERA. Moreover, another dimension of the paper is application of ERA in O&G. Thus, let's review the tools, then recent ERA applications reported in the literature.

Many risk assessment semi-quantitative techniques consider only the two major risk measures, i.e., risk probability (or likelihood) and risk impact (or consequence). The seminal and famous technique is P&I (Probability and Impact matrix). For ERA, many techniques act beyond likelihood and consequence. An original technique is SMAUG (Seriousness, Manageability, Acceptability, Urgency and Growth) offered by [5]. This technique suggests 5 measures to rank the environmental hazards. SMUG (Seriousness, Manageability, Urgency and Growth) has been developed by the New Zealand MCDEM (Ministry of Civil Defense Emergency Management) groups [6, 7]. This technique is on the basis of earlier SMAUG. The SMUG was dated February 2006. According to suggest by South Island MCDEM, "urgency" involved in SMUG, was eliminated on two justifications. Firstly, this measure has already been addressed through "seriousness". As a matter of fact, by inclusion of "urgency", "seriousness' is weighted twice. Secondly, for many hazards, it is hard to determine a return period or frequency of occurrence. The New Zealand MCDEM identified seriousness measure in four environmental impacts, i.e., social, built, economic, and natural. By removal of "urgency" from SMUG, a alternative of it was made namely SMG (Seriousness, Manageability, and Growth) [8]. Cunningham [6] (2006) identified a number of issues relating to SMG hazard evaluation. A variant 7-measures hazard analysis technique is FSMAUGO which stands for Frequency, Seriousness, Manageability, Awareness, Urgency, Growth, and Outrage. This technique has been proposed by Institute for International Development [9]. The first two measures "frequency" and "seriousness", are equivalent to "probability' and "Impact" as outlined in AS/NZS 4360 (Australia New-Zealand Standard). Obviously, in comparison previous versions, an additional measure, called "outrage" has been added to the model for inclusion of political and community outcomes of hazards posed even before the impacts. The "outrage" was applied to account for the political aspect of disasters. A technique called US-FEMA (United States Federal Emergency Management Agency) is a hazard evaluation model based on 4 key measures, each with a defined description and weighting guideline. The measures are history, vulnerability, maximum threat, and probability. A hazard evaluation technique, originally designed in the USA in 1997 [10], is called EDRI (Earthquake Disaster Risk Index). In EDRI, the analyst considers five measures as frequency, exposure, vulnerability, external context, and emergency response & recovery capacity. Let's review some risk analysis techniques from technical contexts, a branch of anthropogenic hazards. FMEA (Failure Modes and Effects Analysis) is a technique used to prioritize possible defects on the basis of thee measures: severity, expected frequency, and ability of detection. An FMEA may be carried out on design or process phase, and is applied to provide prompt response actions. According to [10], business triage employes a risk framework known as PIVOT, for its components of Probability, Impact, Vulnerability, Outrage, and Tolerance. It puts the raw risk into a wider context to allow better decisions. There are a variety of other relevant techniques such as Threat and Hazard Identification and Risk Assessment (THIR), Hazard and Operability analysis (HAZOP), Hazard analysis (HAZAN), Hazard Identification (HAZID), Hazard Identification and Risk Assessment (HIRA), Hazard and Risk Analysis (HARA), Structured What-If Technique (SWIFT), Process Hazard Analysis (PHA), Occupied Building Risk Assessment (OBRA), Energy Trace and Barrier Analysis (ETBA), Block Diagramming Method (BDM), Risk Based Inspection (RBI), Project Definition Risk Index (PDRI), Risk Function Development (RFD), Data Precision Ranking (DP), Failure Modes, Effects and Criticality Analysis (FMECA), Fine Kinney method, Safety and Critical Effect Analysis (SCEA), Management Oversight and Risk Tree (MORT), and TRIPOD Beta.

Nazrul-islam et al. [11] used an integrated technique consisting of SMUG and FEMA for prioritizing hazards related to community-based disasters in Bangladesh. Lawrence and Hyginus [12] employed the SMUG in prioritization of building construction hazards in Owerri municipality of Imo State Nigeria. The results of that research showed that falls from height, poor quality materials and unprotected workers are the most common hazards in the building construction activities within Owerri Municipality. Abtahi et al. [13] used FEMA for risk assessment in oil and gas assets of the border provinces. They identified and evaluated vulnerabilities and the risk of each asset, after that, provides solutions to reduce the risk in the oil and gas infrastructure of the border provinces. Shafiei-Moghaddam et al. [14] carried out a Natesh hazard assessment in potential earthquake risk scenarios by using a semi-quantitative method. The reference scenario was achieved employing SMUG model. Some of their findings were legislation together with hazard mitigation, planning for transfer of potentially dangerous industries to outside urban zones, and enhancing the coordination among the government, industries, and people in the management of hazards. Karagiorgos and Grahn [15], examines the development of the US-FEMA model, highlighting major challenges and effective approaches identified during its development. They used a semi-structured interviews with FEMA officials and contributing SMEs (Subject-Matter-Experts) to perform their study. Peyro and Masihi [16] applied R-FMEA (Risk FMEA), to diagnose, assess, and prioritize risks in CEOR (Chemical Enhanced Oil Recovery). Through a literature review and SME surveys, 26 major risks were diagnosed and clustered into four classes. Jing et al. [17] compiled seismic failures of pipelines from major seismic zones in China. They developed a failure probability pattern that integrates geotechnical parameters, structural responses, and ground motion features to evaluate impact of liquefaction, site amplification, fault activity, and collapse/landslide events.

3. Research Gap

From the literature review, it is revealed that there is no comprehensive model that have considered different risk measures (sometimes called risk attributes, risk criteria, risk characteristics, risk parameters, or risk dimensions). Reviewing various definition of risk (e.g., the chance of something happening that will an impact upon objectives, suggested by AS/NZS 4360 [18]; the probability of occurrence of loss multiplied by its respective magnitude, proposed by Jaafari [19]; an uncertain event or condition that, if it occurs, has an effect on an objective, proposed by PMI in 2013) [20], we find out that most of literature have concentrated on only two famous measures, i.e., risk probability and risk impact. By the way, there are some ERA techniques that characterize hazards using another driving measures along with consequence and probability. For example, SMG model, consists of three risk measures , i.e., risk seriousness (or risk impact), risk manageability, and risk growth. Thus, there is a requirement for establishing a comprehensive model to inclusion of various risk measures in ERA. An important matter is this fact that semi-quantitative techniques (like, SMUG, FMEA, etc.) should not be used, unless methods for rating (or scaling) their elementary measures are established. Considering this fact, another gap of the ERA literature, is in establishment of Risk Rating Tables (RRT) (see Table 1 for an instance) for describing level of a risk measure. According to the mentioned gap, there is no unique model including complete RRTs for different risk measures.

4. Methodology

In before section, we concluded that there are two major shortages in the relevant literature of ERA techniques: absence of a model containing different risk measures, and lack of a unique model including complete RRTs for each risk measures . Based on these gaps, the research procedure is designed in 5 stages as shown in Figure 1. Let us provide some explanations on stage 2. A RRT is formed for a risk measure (probability, impact, detection, etc.) as a guideline for selecting the desired level of the risk on that measures. Table 1 represents a sample of RRT for risk legal impact, with 5 categories. In a typical

RRT, the qualitative level of measure is usually determined based on the description of the characteristic conditions or on the basis of the relevant actual quantitative values. A RRT can be considered as a pattern for SMEs to make a standard framework to give the comments. Moreover, the degree of risk tolerance (risk-averse, risk-seeker, or risk-neutral) SMEs can be taken into account in these tables. Let's accept two rules: (I) A RRT should formed in an odd number of categories, i.e., 3, or 5, or 7, or 9, and so on, and (II) the categories should be sorted from the bottom to top of RRT, according to the importance/criticality of the hazard regarding the measure. For example, in risk probability RRL, "very probable" should be inserted at bottom of the table, and "very unlikely "category should be inserted at top of the table.

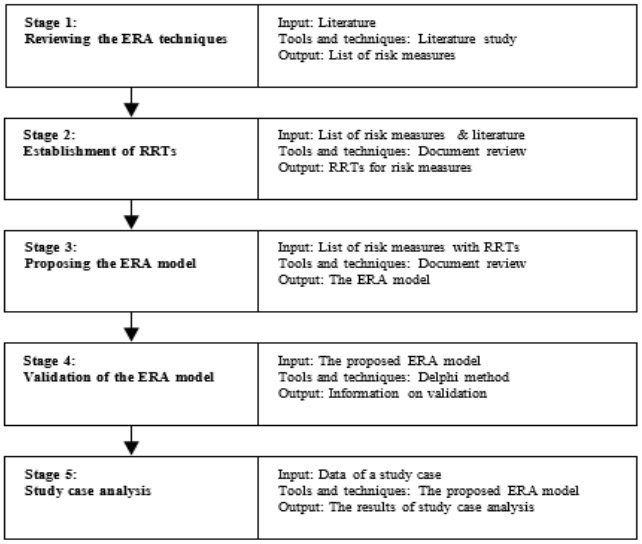


Figure 1. The procedure used in this work.

Table 1. An instance of RRT for legal impact of hazards.

Name	Description
Insignificant	No legal impacts.
Minor	Little non-compliance with funding agreement and breaches of regulation. Breach of applicant protocols.
Moderate	Important breach of regulation consisting of investigation by or reporting to authority with prosecution powers. potential for moderate fine. Breach of funding agreements terms and conditions.
Major	Major breach of funding agreement or relevant legislation/regulations.
Severe	Breach incurring considerable prosecution, with potential for significant fines.

5. The Proposed Model

The proposed model consists of four elements, i.e., (I) a list of various risk measures, (II) a straightforward risk maturity model, and (III) a flexible guideline for ranking hazards.

5.1. Risk Measures

Herein, using literature review, the identified risk measures are displayed in Table 2.

5.2. Risk Maturity Model

The proposed risk maturity model enables the ERA analysts to determine the maturity level they are in. This model is a guideline to draw a proper roadmap for activities under ERA. It also makes the ERA analysts easier to share better practices across others. Table 3 shows the proposed risk maturity model. This model has three level.

Table 2. Risk measures.

Name	Description	Category	Characteristic Question
Impact	The relative impact of a hazard, in terms of financial, physical, social, economic, or number of people affected, etc. Risk seriousness, risk severity, risk outcome, and risk consequences are synonyms for risk impact.	After occurrence	What is the expected outcome of the hazard?
Vulnerability	The potential of physical, social, economic, or any environmental items to be harmed, destructed, damaged, disrupted or other form of loss within occurrence of the hazard.	After occurrence	How exposed environment may be affected by the hazard?
Exposure	The extent/size/quantity of things that affected by the hazard. Sometimes it is called risk contagion.	After occurrence	May the hazard impact on a one item, some items, or the entire system?
Manageability	The ease with which the hazard can be prevented by influence on probability of the hazard.	Handling options	Can anything be done about the hazard, before occurring?
Controllability	The ease with which the hazard can be mitigated by influence on impact of the hazard.	After occurrence, Handling options	Can the hazard outcomes be reduced after occurring?
Urgency	The degree of criticality to implement a mitigation measure to address the hazard, after happening.	After occurrence, Time	How critical it is to address the hazard?
Growth	The potential or rate at which the hazard will increase.	After occurrence	If nothing is done about the hazard, will it grow worse or remain as it is?
Probability	The probability of the hazard to occur. Risk likelihood, risk chance, risk occurrence, and risk frequency are synonyms for risk probability.	Before occurrence	How likely is the hazard to materialize?
Visibility	The possible chance of observing a potential hazard, before occurrence.	Before occurrence	Can the hazard, be identified, before occurring?
Detection	The degree to which a hazard be detected after occurrence.	After occurrence	Can the hazard be identified after occurring?
Timeframe	The timeframe in which the hazard expected to be occurred.	Before occurrence, Time	When is the hazard likely to happen, near of far?
Effect delay	The period between the hazard happening and its actual impacts. Sometimes it is called risk velocity.	After occurrence, Time	If impacts of the hazard are activated right after its occurrence or later?
Awareness	The level of awareness of the hazard posed within related stakeholders.	All aspects	Has community or any stakeholder adequate information about the hazard?
Outrage	Stakeholders' expressions/believes around inadequacy of response actions and preparedness for the hazard.	After occurrence, Handling options	To which extent, has community or any stakeholder trust on the hazard management?

Table 3. Risk maturity model.

Code	Level	Description
B	Basic	System can identify and address hazards just for critical situations. It has a simple ongoing plan for risk management. There are some weaknesses such as lack of history of assessment hazards, lack of previous root cause analysis for hazards, and lack of follow-up on identified hazards.
M	Managed	System can identify and address hazards for all possible situations. It has assigned owners to core processes for ERA purposes. The ERA analysts pay attention at least the best practices such as using SME's opinions to identify and address hazards, analyzing findings for risk level. Once a hazard is identified, investigated, and addressed, the system applies corrective/preventive handling options. There are not weaknesses in basic level.
A	Advanced	Risk management is incorporated into the systems' culture, decision making procedures, and policies. In addition to the features mentioned in managed level, the ERA analysts have training in many disciplines such as root cause analysis, different tools and techniques (e.g., FMEA and SMUG), and how to effectively monitor the hazards through a continues process.

5.3. The Procedure

In this sub-section, let's see the course of action of the proposed model. The model suggests taking the following stages:

Stage A. The ERA analyst should pay attention to his/her real case/situation, and owing to all the facts in his/her system/organization, choose the best level of maturity level explained before in Table 3.

Stage B. The ERA analyst selects a set of desirable risk measures from Table 2. The recommendation is selection of at most 3 measures for maturity level "B", and at most 6 measures for maturity level "M".

Stage C. The ERA analyst establishes RRTs for measures. As the model's advice, the number of categories in RRT should be 3, 5, and 7, when maturity level is "B", "M", or "A", respectively. Notably, the analyst may provide several number of RRTs for a given measure. For instance, there are many kinds of risk impact, such as financial impact, number of injuries, political impact, or even impact on reputation of organization, thus the analyst establishes one RRT for each kind of impact.

Stage D. According to the level of maturity, one of the below approaches is performed:

- **For "A" level: Outranking approach**: The ERA analyst rates each measure using a qualitative scale. For instance, the qualitative scale in 5-category form is VL, L, M, H, and VH (Very Low, Low, Medium, High, and Very high). Once a relative rating has been allocated to all hazards according to the selected measures, the list of hazards is reviewed. Those with the most VH are the hazards that warrant priority attention, in case of tie, those with the most H are placed ate top of the list, again in case of tie, the hazards with the most M are most important, and so on.
- **For "M" level: Semi-qualitative approach**: This approach indicates assigning an ordinal numerical score such as 1, 3, 5, 7, and 9 to VL, L, M, H, and VH, respectively. Now, an overall score for a hazard is calculated by summation of all the individual scores for measures. This overall score can be used to compare different hazards, and to ranking them.
- **For "A" level: Quantitative approach**: This form of the evaluation is a deep way to rank the hazards. Each hazard is dedicated a rate from interval [0 1]. in a way that 1 shows the most critical condition, and 0 depicts the opposite state. After that, each measure is assigned a numerical weight, between 0 and 1, showing proportional importance of measures. The weights are assumed to add up to 1. At the end, weighted summation of the rates is calculated for each hazard. This overall number displays the importance level of hazard on the interval 0 to 1. For estimation of the above-mentioned weights for the measures, there are many relevant methods in the state-of-the-art of MADM (Multiple Attribute Decision Making). The proposed methodology advises using the ROL (Rank Order Logarithm) developed by Hatefi [20]. In this method, simply the analyst first subjectively rank the measures. Then, Equation (1) is used to determine the weights. In the formula, the weight of the measure at rank j is denoted by w_j, and n represents the total number of the measures.

$$w_j = \frac{\ln(j) - \ln(n+1)}{\ln(n!) - n\ln(n+1)}, \quad j = 1,2,..,n. \qquad (1)$$

6. Validation

A Delphi evaluation has been used for validation of the suggested model of ERA. Four online Delphi meetings have been performed by 16 SMEs with adequate skills/educations/experiences in the risk analysis areas, especially ERA. After describing the elements and process of the ERA model, the SMEs gave his/her judgments by assigning a number ranges from 0% to 100%. Moreover, the SMEs were asked to state the reasons for their idea. The mean and the standard deviation of the numbers were 86.24 and 7.86 that are acceptable and considerable statistics. The key terms expressed by the SMEs were (a) very comprehensive, (b) good structure, (c) easy to employ, and (d) easy to customize.

7. Study Case

In an downstream real case from an O&G firm, the hazardous chemical storage room was asked to be assessed from the view of adverse hazards. The major hazardous chemicals in the room were the materials such as Acetic acid, Methanol, Oleum, Hexane, Toluene, Acetonitrile, Acetone, Benzene, Methylene dichloride, and Acetonitrile. All these chemicals were in liquid form, flammable, toxic, and stored in different tanks. According to the performed study, four hazards were identified as:

⊕ Fire
⊕ Explosion (vapor cloud explosion)
⊕ Leakage
⊕ Toxic hazard

According to the standard instructions, the storage manager knew that he should taken the hazards into consideration because some of the chemical features about the flammability, toxic, corrosive and explosion properties of them. His ERA analyst specifies that the firm is at a "M" level of maturity. He makes decision to rank hazards by incorporating only three measures as (I) risk visibility, (II) risk impact on assets, bidding and labors, and (III) risk probability. The RRTs he was provided, are shown in Table 4, Table 5, and Table 6.

Table 4. The RRT for risk visibility.

Name	Score	Description
Very visible	1	With a probability of 0 to 20 percent, the hazard cannot be detected before occurring.
Good	3	With a probability of 20 to 40 percent, the hazard cannot be detected before occurring.
Moderate	5	With a probability of 40 to 60 percent, the hazard cannot be detected before occurring.
Poor	7	With a probability of 60 to 80 percent, the hazard cannot be detected before occurring.
Very invisible	9	With a probability of 80 to 100 percent, the hazard cannot be detected before occurring.

Table 5. The RRT for impact of hazard on air.

Name	Score	Description
Negligible	1	After the occurrence of the hazard, the conditions have almost no threat to the safety and building of the storage.
Normal	3	After the occurrence of the hazard, the conditions have minimal threat to the safety and building of the storage.
Marginal	5	The occurrence of the hazard may cause or result in some labor injuries, prominent property loss or degraded and compromised conditions in the storage.
Critical	7	The occurrence of the hazard may cause severe labor injuries with no death, but major property loss or significant adverse impact on the storage building.
Catastrophic	9	The occurrence of the hazard may result in many labor death; grave labor injuries; large scale destruction in room and facilities of the storage.

Table 6. The RRT for risk probability.

Name	Score	Description
Rare	1	The hazard will just occur in exceptional situations.
Unlikely	3	The hazard is expected to occur in most situations.
Probable	5	The hazard will probably occur in most situations.
Likely	7	The hazard might occur at some time.
Almost certain	9	The hazard is not expected to occur in most situations.

Finally, the the firm's chemists and engineers (as SMEs) taken part is a meeting to determine the scores. The results of consensus via the SMEs is shown in Table 7.

Table 7. Risk maturity model.

Hazard	Visibility	Impact	Probability	Total	Rank
Fire	3	5	3	11	3
Explosion	7	9	1	17	1
Leakage	7	1	3	11	3
Toxic hazard	1	5	7	13	2

8. Conclusions

The paper started to show that there is a limited study on gathering different risk measures, and construction of proper and useful RRTs for evaluation of hazards in ERA. The paper proposed a new generic framework to organize all the risk measures, with aim of indispensable shifting of risk analyst's perspectives toward a complete view to all the aspects of hazard measurement. Application of the proposed model was examined in an O&G-related study case, through which productive application of the proposed model was demonstrated. The paper concludes that the proposed idea can be benefited for ERA analysts in most effective and productive manner in real world's situations. As the future studies, the recommendations are: (I) Integrating the proposed model with MADM methods, (II) Application of the proposed model in areas such as software engineering and financial systems, and (III) Using novel AI (Artificial Intelligence) areas to enhance the productivity of the proposed model, e.g., designing EI (Expert Systems) based on the model.

Credit Authorship Contribution Statement

Mohammad Ali Hattefi: Supervision, Project administration, and Manuscript writing and editing results.

Conflicts of Interest

The authors declare that they do not have any personal or financial conflicts of interest.

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