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A state-of-the-art literature review of Fine–Kinney occupational health and safety risk assessment method

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Abstract

Occupational health and safety risk assessments are crucial in managing workplace hazards and minimizing the associated risks and financial losses from work-related diseases and accidents. Among the widely applied methods, the Fine–Kinney risk assessment approach has gained prominence in industrial and academic contexts. Despite several literature reviews on occupational risk assessment, none have explicitly focused on Fine–Kinney. This study addresses this gap through a comprehensive bibliometric analysis and critical literature review of 95 studies retrieved from Scopus and Web of Science. The analysis explores research trends, theoretical advancements, application areas, and future opportunities for the Fine–Kinney method. The findings reveal significant growth in its usage, particularly in hybrid approaches combining Multi-Criteria Decision-Making (MCDM) techniques and fuzzy logic. The study also identifies gaps, particularly in sectors like agriculture, aviation, and disaster management, where the method remains underutilized. The results provide valuable insights for advancing the Fine-Kinney method through methodological innovations and extending its applicability to new fields.

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Nomenclature

| Full version of the technique / method / concept | Abbreviation |
|--|----------------|
| Activity based costing | ABC |
| Analytic hierarchy process | AHP |
| Fuzzy analytic hierarchy process | FAHP |
| Pythagorean fuzzy analytic hierarchy process | PFAHP |
| Interval valued intuitionistic fuzzy analytic hierarchy process | IVIFAHP |
| Spherical fuzzy analytic hierarchy process | SFAHP |
| Vise Kriterijumska Optimizacija I Kompromisno Resenje | VIKOR |
| Fuzzy Vise Kriterijumska Optimizacija I Kompromisno Resenje | FVIKOR |
| Pythagorean fuzzy Vise Kriterijumska Optimizacija I Kompromisno Resenje | PFVIKOR |
| Interval type-2 fuzzy Vise Kriterijumska Optimizacija I Kompromisno Resenje | IT2FVIKOR |
| Multi-objective optimization on the basis of ratio analysis | MULTIMOORA |
| Hesitant fuzzy multi-objective optimization on the basis of ratio analysis | HFMULTIMOORA |
| Interval valued intuitionistic fuzzy multi-objective optimization on the basis of ratio analysis | IVIFMULTIMOORA |
| Relative preference relation based triangular fuzzy number | RPRBTFN |
| Failure mode and effect analysis | FMEA |
| Fuzzy inference system | FIS |
| Fuzzy comprehensive evaluation method | FCEM |
| Interactive multi-criteria decision making (Portuguese acronym) | TODIM |
| Intuitionistic fuzzy interactive multi-criteria decision making (Portuguese acronym) | IFTODIM |
| Generalized interval type-2 fuzzy interactive multi-criteria decision making (Portuguese acronym) | GIT2FTODIM |
| Fuzzy rule-based system | FRBS |
| Grey relation analysis | GRA |
| Best worst method | BWM |
| Fuzzy best worst method | FBWM |
| Bayesian best worst method | BBWM |
| Fuzzy multi-attributive ideal-real comparative analysis | FMAIRCA |
| Process capability | PC |
| Environmental affect and environmental quality ratio | EOR |
| Autoregressive integrated moving-average | ARIMA |
| Adaptive network based fuzzy inference system | ANFIS |
| Step-wise weight assessment ratio analysis | SWARA |
| Fuzzy step-wise weight assessment ratio analysis | FSWARA |
| Complex proportional assessment of alternatives | COPRAS |
| Fuzzy complex proportional assessment of alternatives | FCOPRAS |
| Pythagorean fuzzy complex proportional assessment of alternatives | PCOPRAS |
| Spherical fuzzy complex proportional assessment of alternatives | SFCODAS |
| Fuzzy fault tree analysis | FFTA |
| Technique for order preference by similarity to the ideal solution | TOPSIS |
| Fuzzy technique for order preference by similarity to the ideal solution | FTOPSIS |
| Interval type-2 fuzzy technique for order preference by similarity to the ideal solution | IT2FTOPSIS |
| Spherical fuzzy technique for order preference by similarity to the ideal solution | SFTOPSIS |
| Kemeny median indicator ranks accordance | KEMIRA-M |
| Quality function deployment | QFD |
| Interval type-2 fuzzy qualitative flexible | IT2FQUALIFLEX |
| Élimination Et Choix Traduisant la Réalité (in French) | ELECTRE |
| Q-rung orthopair fuzzy number | q-ROFN |
| Probabilistic linguistic term sets | PLTS |
| Organization, Rangement Et Synthèse De Données Relationnelles (in French) | ORESTE |
| Decision making trial and evaluation laboratory | DEMATEL |
| Analytic network process | ANP |
| Gained and lost dominance score | GLMS |
| Maclaurin symmetric mean operator | MSMO |
| Fermatean fuzzy measurement of alternatives and ranking according to compromise solution | FFMARCOS |
| Compromise ranking of alternatives from distance to ideal solution | CRADIS |
| Weighted power average operator | WPAO |
| Intuitionistic fuzzy weighted averaging operator | IFWAO |
| Hesitant fuzzy linguistic term set | HFLT |
| Fuzzy compromise ranking of alternatives from distance to ideal solution | FCRADIS |
| Combined compromise solution | CoCoSo |
| Fermatean fuzzy analytic hierarchy process | FFAHP |
| Fermatean fuzzy weighted aggregated sum product assessment | FFWASPAS |
| Interval valued spherical fuzzy technique for order preference by similarity to the ideal solution | IVSFTOPSIS |
| Fuzzy additive ratio assessment | FARAS |

1. Introduction

The Fine-Kinney is a risk assessment method that was first proposed by William T. Fine in a report (Fine, 1971) and later introduced in detail in a report entitled "Practical risk analysis for safety management" by G. F. Kinney and A. D. Wirut (Kinney and Wiruth, 1976). Although the method was not widely discussed in academic literature, it has become a method that is frequently used and applied in industry circles. It is a systematic and easy-to-use method that mathematically deals with the risks arising from hazards. The risk posed by a particular hazard may be taken as increased by (1) the probability of the hazardous event occurring (P), (2) exposure to that event (E), and (3) the likely consequences of that event (C). Numerical values are assigned to each of these three factors for risk calculation. A risk score is then calculated by multiplying these three separate factors. The risks with higher risk scores are considered more crucial and thus should be paid more attention to in terms of risk mitigation. Depending on the score obtained by multiplying the values of the three factors, five different risk situations (classes) are obtained: risk, possible risk, substantial risk, high risk, and very high risk. One can refer to the details of the Fine–Kinney method and its implementation steps (Gul et al., 2021). Although it has been a method frequently used in the industry since it was first proposed in the 1970s, the Fine–Kinney method appeared in the academic literature in the last ten years.

Since 2015, several innovations and refinements have emerged to address the method's limitations and enhance its applicability in modern risk management contexts. Similar limitations of the method, especially in classical techniques such as the 5x5 matrix method, failure mode and effect analysis (FMEA), hazard and operability analysis (HAZOP), enabled researchers to develop new methods to eliminate them and to use new concepts with this method (Liu et al., 2019). In the years following 2015, researchers began addressing the rigid structure of Fine–Kinney by integrating it with other risk assessment tools and techniques, such as fuzzy logic and Multi-Criteria Decision-Making (MCDM) methods (Zhu et al. 2019; Ersoy et al. 2019; Wang et al. 2018; Gul et al. 2018a; Gul et al. 2018b; Gul et al. 2017). These hybrid approaches were developed to improve the subjective nature of risk factors in Fine–Kinney. For instance, Fuzzy Fine–Kinney emerged as a popular modification, allowing for a more flexible interpretation of risk levels by handling uncertainty and imprecision in expert judgments (Yang et al. 2019; Gul and Celik, 2018; Karasan et al. 2018). Further, methods like Analytic Hierarchy Process (AHP) combined with Fine–Kinney were developed to prioritize risks based on expert input and make the method more adaptable to complex scenarios, particularly in industrial safety applications (Yilmaz and Selim Ozcan, 2019; Zhang et al. 2019; Karasan et al. 2018; Gul et al. 2018a; Ilbahar et al. 2018; Gul et al.

2018b; Gul et al. 2017; Kokangül et al. 2017). These methods are frequently used to determine the importance of the weight of the three existing factors (P, E and C) and the risk ranking of hazards (Gul et al., 2021). In addition, “fuzzy logic theory” is used in combination with these methods to reveal the uncertain risk perception of decision makers in risk assessment and to overcome the difficulty of obtaining precise data (Wang et al., 2023a; 2023b).

In the period following 2020, referred to as the “Enhanced computational models and AI integration” era, research efforts concentrated on applying fuzzy set extensions (Tatar et al. 2023; Wang et al. 2023; Elidolu et al. 2022; Seker, 2022; Çalış Boyacı and Selim, 2022; Hacibektasoglu et al. 2021; Gul et al. 2021; Tang et al. 2021; Gul and Ak, 2020; Gul, 2020; Efe and Efe, 2023; Satici and Mete, 2024; Bayhun and Demirel, 2024; Ayvaz et al. 2024; Ak and Demir, 2024; Wang et al. 2024; Soltani et al. 2023), artificial intelligence and data mining techniques (Dagsuyu et al. 2020; Luo et al. 2020; Baç and Ekmekci, 2020) to improve the predictive capabilities of the Fine–Kinney model. Researchers employed machine learning algorithms to automatically assess risks, reducing human biases inherent in traditional risk evaluation. AI-driven Fine–Kinney models showed promise in predicting potential hazards in dynamic environments such as manufacturing and construction sectors. Bayesian networks were also integrated with Fine–Kinney to improve risk prediction by accounting for probabilistic dependencies among risk factors, making it suitable for industries with highly interconnected processes (Gul et al. 2022). Fine–Kinney method has also been applied in sustainability contexts, reflecting the growing importance of environmental risk assessment (Cruz Netro et al. 2018; Bayhun and Demirel, 2024). Approaches emerged to evaluate risks in terms of environmental sustainability, often linked with life cycle assessments to analyze the broader impact of industrial activities on ecosystems. Moreover, there has been an emphasis on digitalizing the Fine–Kinney framework, allowing for real-time risk monitoring (Cardoso et al. 2024). This digital transformation has enabled the method to evolve into a more dynamic, continuous risk assessment tool rather than a static evaluation (Li et al. 2024; Ayvaz et al. 2024; Tang et al. 2024; Wang et al. 2024).

From 2015 to 2024, it has undergone significant evolution, from its foundational framework to hybrid approaches combining fuzzy logic, AI, and digital tools. These advancements have expanded its scope, allowing it to be applied across various industries, from traditional occupational safety to emerging fields like sustainability and intelligent transport systems. This journey reflects the broader trend in risk management research towards flexibility, computational sophistication, and real-time adaptability.

Although there is a short literature review chapter covering 19 studies in Gul et al. (2021)'s book, a comprehensive literature review has not yet been presented to the best of the authors' knowledge to show the increasing popularity of the Fine–Kinney method in the academic literature in recent years, to reveal the research gaps, and to make visible the aspects of the method that are open to improvement. Starting from this point, this critical state-of-the-art review aims to investigate 95 academic studies (including journal articles, conference proceedings, and book chapters) till now. Data was sought through Scopus and Web of Science (WoS) databases. The studies were reviewed and categorized based on either the stand-alone Fine–Kinney method (Single usage) and extensions of the Fine–Kinney with more than one techniques/ methods/ concept (Hybrid usage). This paper also presents an overview of the risk factors, risk factor weighting methods, risk assessment methods, fuzzy set usage, type of fuzzy extension, and shortcomings of Fine–Kinney used in the reviewed studies. Moreover, we analyze the selected studies from the bibliometric view, such as the publication trend, the most popular MCDM approach for Fine–Kinney, the most influential research, the published journals, the country of origin for the studies, and the subject areas.

The rest of the study is organized as follows. The content of the traditional Fine–Kinney method and its prominent shortcomings are given in section 2. Section 3 describes the research methodology used for the Fine–Kinney literature review study. Section 4 provides the numerical results of both the bibliometric and critical state-of-the-art literature review and also addresses open problems, solutions, improvements, and future-study opportunities for researchers. In the last section, general results and inferences are given.

2. Overview of the Fine–Kinney method: strengths and limitations

Fine–Kinney is a quantitative, easy-to-use, and easy-to-understand risk assessment technique that can be applied to all manufacturing and service industry areas. The first step in implementing this method is to identify the hazards and risks that may lead to undesirable results through a systematic brainstorming session. After that, the value scales of the three risk factors, probability, exposure, and consequence, are determined. Although the numeric values for each factor are arbitrarily chosen, they are internally consistent and provide a realistic but relative score for overall risk (Kinney and Wiruth 1976; Gul et al. 2021a). They have different scales: the probability factor is 7, and the exposure factor and the consequence factor are 6 per each. For the probability factor, the scale starting with "visually impossible (0.1)" continues with "practically impossible (0.2)", "conceivable but very unlikely (0.5)", "only remotely possible (1)", "unusual but possible (3)", "quite possible (6)", and "might well be expected (10)". For the exposure factor, 0.5 is assigned to a very

rare exposure, which means yearly exposure. Then, 1, 2, 3, 6, and 10 values are assigned to rare, unusual, occasional, frequent and continuous exposures, respectively. The greater the exposure to a potentially hazardous condition, the greater the risk. The scale values have a higher value range for the consequence factor than the other two factors. For example, the noticeable situation is taken as 1 corresponding for an incident classified as a minor first aid accident. Then, 3, 7, 15, 40 and 100 values are assigned for the important, serious, very serious, disaster and catastrophic situations, respectively (Kinney and Wiruth, 1976).

The studies of (Fine, 1971) and Kinney and Wiruth (1976) are generally taken as a basis for this method. The values of these factors are presented in Table 1 in detail. Then, the Risk score (RS) = $P \times E \times C$ formula provides scores for each risk. The next step is the determination of preventive actions. For this, the priority value of the risks is considered. Hazards are prioritized in descending order of RSs. After that, recommended control measures for high-risk hazards should be considered.

The Fine–Kinney method, which is easy to use, does not require much expertise and can be performed without requiring an extensive team. It is ostensibly applicable and beneficial for industrial environments. However, it needs improvement and development due to the many handicaps it contains in risk score calculation (Gul et al., 2022; Gul et al., 2021a; Çalış Boyacı and Selim, 2022; Boyacı et al., 2021; Gul et al., 2022; Gul et al., 2018a; Gul et al., 2018b; Derse, 2021; Wang et al., 2022a; Wang et al., 2022b; Gul and Celik, 2018). These drawbacks can be listed as follows:

- Neglecting the relative importance weight of the three fundamental parameters (P, E, and C) used in the RS calculation is the most critical handicap. Such a weight of importance is not considered in the classical Fine–Kinney.
- As with the primary risk assessment method known as FMEA, the fact that the various combinations of the three risk parameters P, E and C of the Fine–Kinney method are equal to the same RS value causes errors in disclosing the actual state of the risks. Their meanings under risk effects can be completely different. Such a handicap may lead to some high-risk hazards going unnoticed.
- The idea that the mathematical operation for calculating RS in classical Fine–Kinney rests on an accurate and solid scientific basis is unfounded. There is no scientific reason why multiplication should be done.
- In the classical Fine–Kinney method, the interrelationships between hazards and causes of hazards have not been sufficiently discussed. For example, hazards are handled and

evaluated independently, regardless of interactions, such as in the Bayesian Networks (BNs).

- The “P, E and C” parameters are analyzed using a scale with discrete measurement values. The classical method does not recommend using a more meaningful and sensitive scale (such as fuzzy, etc.).
- RS is calculated based on only three risk factors, mainly concerning occupational safety. Although other parameters, including cost, were added in Kinney and Wiruth (1976), it does not include additional factors that can define risk and impact the classical Fine–Kinney risk calculation. However, sometimes, it is possible to create a hierarchy in the form of sub-factors under these three factors and create a more meaningful framework. Again, it is an important handicap that factors such as prevention, the sensitivity of not using personal protective equipment, the sensitivity of not performing maintenance, and not being detected are not covered.

The formula used in classical Fine–Kinney RS calculation is sensitive to changes in the values of risk parameters. For example, a small change in the value of any of the three risk parameters leads to a very different change in the RS value.

Table 1. Suggested ratings for P, E and C factors of a hazard in the Fine–Kinney method

| Scale of probability (Fine, 1971) | | Scale of probability (Kinney and Wiruth, 1976) | |
|--|---------------|--|---------------|
| Description | Rating/ Value | Description | Rating/ Value |
| The most likely and expected result | 10 | Might well be expected | 10 |
| Quite possible, would not be unusual | 6 | Quite possible | 6 |
| An unusual sequence or coincidence | 3 | Unusual but possible | 3 |
| A remotely possible coincidence | 1 | Only remotely possible | 1 |
| Extremely remote but conceivably possible | 0.5 | Conceivable but very unlikely | 0.5 |
| Practically impossible sequence or coincidence | 0.1 | Practically impossible | 0.2 |
| | | Virtually impossible | 0.1 |

| Scale of exposure (Fine, 1971) | | Scale of exposure (Kinney and Wiruth, 1976) | |
|---|---------------|---|---------------|
| Description | Rating/ Value | Description | Rating/ Value |
| Continuously (or many times daily) | 10 | Continuous | 10 |
| Frequently (approximately once daily) | 6 | Frequent (daily) | 6 |
| Occasionally (once per week—once per month) | 3 | Occasional (weekly) | 3 |
| Unusually (once per month—once per year) | 2 | Unusual (monthly) | 2 |
| Rarely (it has been known to occur) | 1 | Rare (a few per year) | 1 |
| Very rarely (not known to have occurred) | 0.5 | Very rare (yearly) | 0.5 |

| Scale of consequence (Fine, 1971) | | Scale of consequence (Kinney and Wiruth, 1976) | |
|--|---------------|---|---------------|
| Description | Rating/ Value | Description | Rating/ Value |
| Catastrophe: numerous fatalities; extensive damage (over \$1,000,000) | 100 | Catastrophe (many fatalities, or >\$10 ⁷ damage) | 100 |
| Multiple fatalities; damage \$500,000—\$1,000,000 | 50 | Disaster (few fatalities, or >\$10 ⁶ damage) | 40 |
| Fatality, damage \$100,000—\$500,000 | 25 | Very serious (fatality, or >\$10 ⁵ damage) | 15 |
| Extremely serious injury (amputation, permanent disability); damage \$1000—\$100,000 | 15 | Serious (serious injury, or >\$10 ⁴ damage) | 7 |
| Disabling injuries; damage up to \$1000 | 5 | Important (disability, or >\$10 ³ damage) | 3 |
| Minor cuts, bruises, bumps; minor damage | 1 | Noticeable (minor first aid accident, or >\$100) | 1 |

3. Research methodology

The research methodology outlined in Figure 1 was followed in this study. This framework can be explained in three stages. The first stage is the data collection stage. The two most important academic databases, Web of Science (WoS) and Scopus were searched. These databases were chosen because they are the peer-reviewed literature's largest abstract and citation databases. TITLE-ABS-KEY (fine-kinney OR fine AND kinney OR fine AND kinney OR fine-kinney OR fine-kinney AND method OR fine AND kinney AND method) was determined as the query for screening. As a result of the first search, 91 studies were identified in Scopus and 61 studies in WoS. When their relevance was investigated, three studies from both databases were eliminated because they could not meet the inclusion criteria.

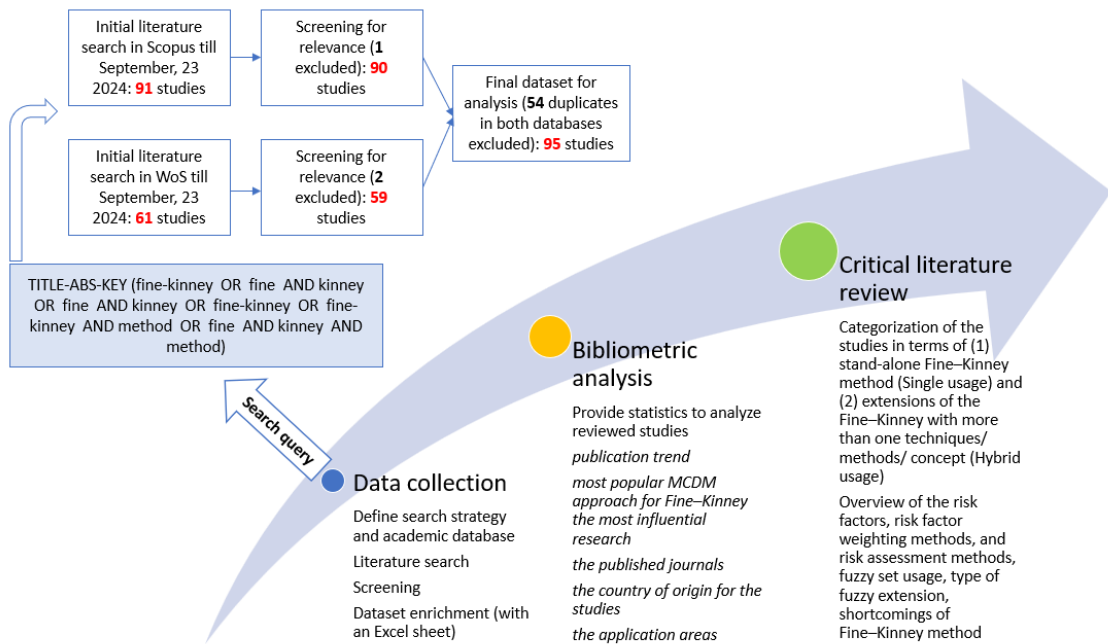


Figure 1. Flowchart of the research methodology

Since 54 studies were displayed (duplicate studies) in both databases, considering this amount, 95 studies that made up the dataset of the study were determined. All studies are published in English. Articles written in a second language are not included.

The second stage examines the obtained data set with a bibliometric analysis. 95 studies are presented with visual tools (Figures and graphs) in terms of elements such as publication trend (Year-wise publication of Fine–Kinney studies), the most popular MCDM approach for

Fine—Kinney, the most influential research, the published journals, the countries of origin and subject areas of the studies.

The third stage is to employ critical literature review. First, studies are included in one of two categories, and further analyses are performed. These categories are the stand-alone Fine—Kinney method (Single use) and extensions of Fine—Kinney using multiple techniques/methods/concepts (Hybrid use). As a result of the categorization, several features, such as the risk factors used in the studies examined, risk factor weighting methods and risk assessment methods, fuzzy sets, fuzzy extension type, and Fine—Kinney's shortcomings are discussed. As a result of these analyzes, a projection is given that will guide the researchers for future studies, such as what the open problems in the occupational health and safety risk assessment studies conducted with Fine—Kinney, what are the features that are open to improvement, and what kind of new approaches would be beneficial to adopt in practice.

4. Results

4.1. Bibliometric analysis results

This section distributes the Fine—Kinney studies into the following bibliometric schemes.

(a) Year-wise publication: Based on the year-wise publication trend graph (Figure 2), here's the interpretation and some numerical inferences: (1) From 2012 to 2018, there was a slow and steady increase in the number of publications. Starting with just 1 paper in 2012, the publications stayed quite low, with 2 papers per year in 2016–2018. This period indicates a gradual interest in the Fine—Kinney risk assessment method, but there hasn't been significant growth during these years. (2) A noticeable rise begins in 2019 with 9 publications, followed by a slight dip in 2020 with 7 publications. However, 2021 marks the peak of publications, with 21 papers, suggesting that this year saw a significant surge in research interest around the Fine—Kinney method. This period may have been driven by new developments or an increased focus on occupational risk assessments, possibly related to broader global industrial or academic trends. (3) After the peak in 2021, the number of publications dropped to 15 in 2022 and 2023. This slight decline still shows sustained interest but at a reduced pace compared to the peak. In 2024, we observe another dip, bringing the number back down to 9 papers. The dotted trendline with the equation $y=1.4164x-2850.9$ and $R^2=0.6409$ shows a general upward trend over the years.

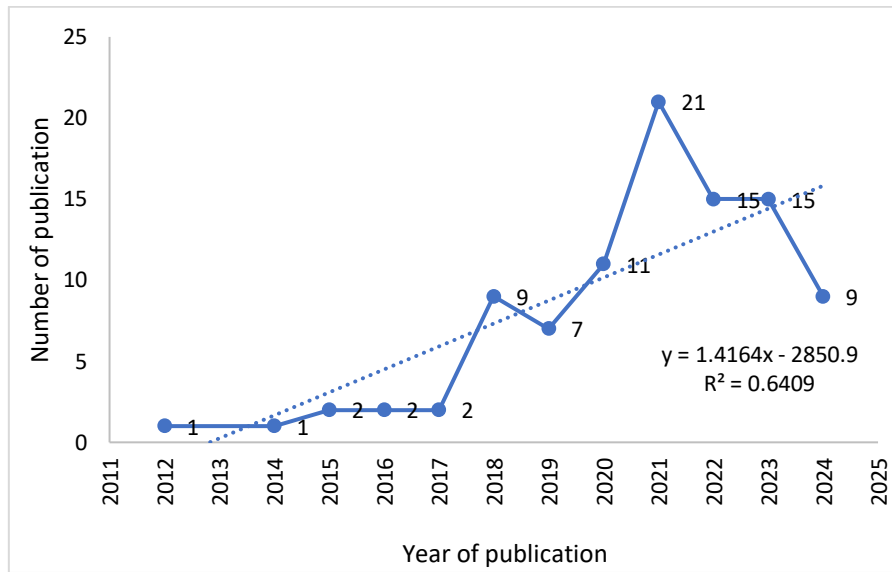


Figure 2. Year-wise distribution of Fine–Kinney studies

The positive slope of the equation (1.4164) indicates that, on average, the number of publications increases by approximately 1.42 papers per year. A value of 0.6409 suggests a moderately strong correlation, meaning that the upward trend in publications is consistent but not perfectly linear. In summary, as shown in Figure 2, Fine–Kinney method saw slow growth in its early years but experienced a rapid rise in interest, especially from 2019 to 2021, reaching its highest publication count in 2021. After the peak in 2021, there's a gradual decline, but research activity remains higher than in the earlier years, indicating sustained academic interest. This can point to future areas for continued research and refinement of the method.

Figure 3 depicts the year-wise and source-type-wise distribution of publications related to Fine–Kinney studies from 2014 to 2024. Journal articles exhibit significant growth over the years. There was a small rise in 2017 (2 articles), followed by a sharp increase in 2018 (9 articles). The peak was in 2021 (14 articles), and it then declined slightly to 8 articles in 2024. The rising number of journal articles shows that Fine–Kinney studies are being formalized and shared within the peer-reviewed academic literature, particularly from 2018 onwards.

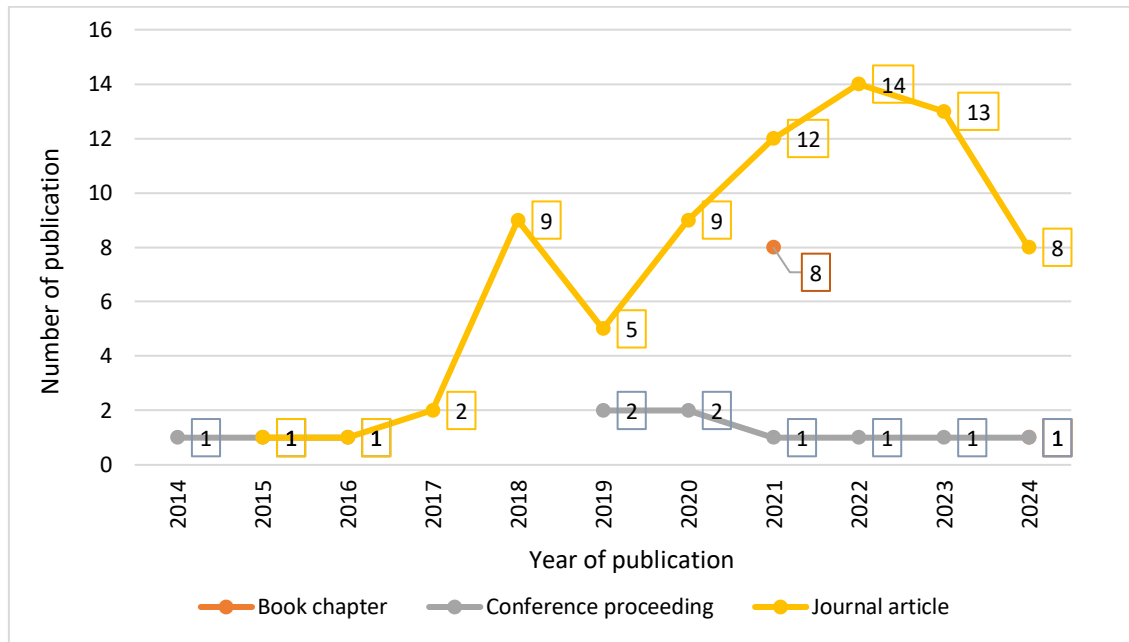


Figure 3. Year and source type-wise publication of Fine–Kinney studies

Conference papers remain fairly stable over time, maintaining a constant low number of 1 to 2 publications per year since 2014, with no significant increase or drop. While there is an active but modest engagement with Fine–Kinney studies at academic conferences, the trend is relatively stagnant compared to the rapid growth in journal articles. The graph shows only a single book chapter published in 2021, with no other publications of this type in the timeline. This suggests limited activity in book contributions. This low engagement indicates that book chapters are not a common medium for disseminating Fine–Kinney research, and journal articles and conference proceedings remain the primary outlets. The graph suggests opportunities for continued growth in journal publications. Despite the decline after 2021, the sustained interest indicates that there is room for further exploration of Fine–Kinney applications in other fields. The low numbers in conference proceedings could imply that more preliminary or exploratory studies should be presented at conferences to stimulate future research.

(b) The most popular MCDM method for Fine–Kinney: Another bibliometric scheme aims to determine which MCDM method is most used with Fine–Kinney. Figure 4 shows the corresponding distribution. The results confirmed that AHP was the most preferred MCDM method when used with the Fine–Kinney method in 17 studies. TOPSIS, VIKOR, TODIM, BWM, Choquet integral, and others follow it.

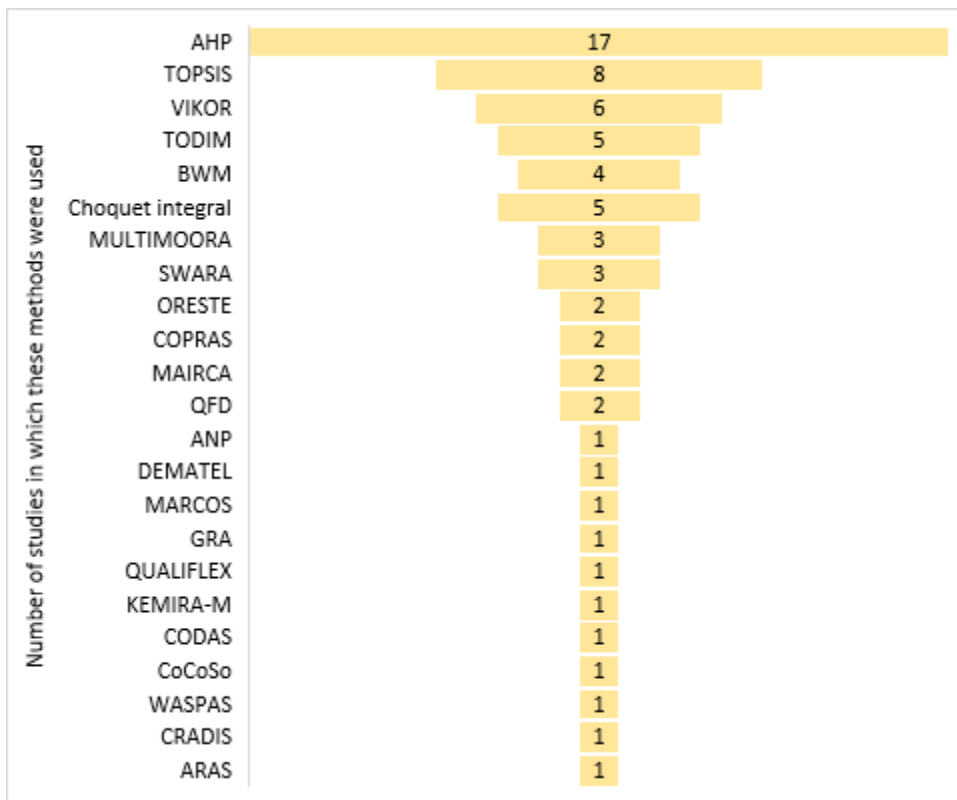


Figure 4. Distribution of the most used MCDM methods in Fine–Kinney studies

AHP, as it is known, is an MCDM method that operates according to the pairwise comparison logic. Since it is one of the oldest methods, it is frequently used in risk assessment (Ashour and Mahdiyar, 2024) and with Fine–Kinney (Gul et al., 2021a). While the simplest version of AHP is used in many studies (Baç and Ekmekci, 2020; Tosik et al., 2023; Yilmaz et al., 2019; Kokangül et al., 2017; Dogan et al., 2022; Yakut et al. 2022; Yang et al., 2020; Derse, 2021; Güney and Kahraman, 2022; Yang et al., 2000), versions combined with fuzzy logic are preferred in many other studies (Tatar et al., 2023; Seker, 2022; Bepary and Kabir, 2022; Gul, 2020; Luo et al., 2020; Zhang et al., 2019; Gul et al. 2018a; Ilbahar et al. 2018; Gul et al. 2018b; Gul et al. 2017; Satici and Mete, 2023;) Fine–Kinney occupational risk assessment studies using pure AHP have generally been studied for the following purposes: (1) to determine the weight of risk parameters, (2) as an alternative risk ranking method against the classical Fine–Kinney, and (3) to determine the importance levels of groups affected by risks.

(c) The most influential study: According to Scopus data, when the most cited Fine–Kinney studies were compiled, Ilbahar et al. (2018) appear to be the most influential study with the highest

number of citations (no. of citations=370). This study discussed a risk assessment study in which Pythagorean fuzzy AHP and fuzzy inference system were integrated for the first time. This study developed a new risk assessment method called "Pythagorean Fuzzy Proportional Risk Assessment (PFPPRA)". For the first time in literature, it was clearly explained within the framework of Pythagorean fuzzy AHP. Pythagorean fuzzy AHP was frequently used in other risk assessment studies conducted after this study. In this respect, it can be said that the study guides the literature and fills a significant gap. This study is followed by the studies of (Kokangül et al., 2017; Karasan et al., 2018; Gul et al., 2018; Gurcanli et al., 2015; Kokangul et al. 2017; Karasan et al. 2018; Gul et al. 2018a; Gurcanli et al. 2015) Most of the top 10 studies regarding the number of citations were published in the journal Safety Science.

(d) Journal-wise publication: Figure 5 presents the distribution of studies according to three different publication sources (journal articles, conference proceedings, and book chapters). A striking result in the distribution of journal articles is that all 38 studies were published in separate journals.

(e) Authors' nationality: Figure 6 shows the distribution of the authors' nationalities in the reviewed 95 Fine–Kinney studies. In this evaluation, the first author's country was considered the original country of the article. According to the results, Turkey ranked first with 55% of all studies, followed by China (18%) and Russia (16%).

(f) Use of Fine–Kinney with other keywords: To monitor the future trend of the Fine Kinney method, we conducted an analysis that included only the years 2022-2024. Via Vos Viewer a co-occurrence and author keyword analysis has been performed, as shown in Figure 7. Larger nodes in the analysis represent terms that appear more frequently in the dataset, indicating their higher usage or citation within the research context.

The red cluster contains the most prominent decision-making methods, with AHP and TOPSIS being the leading approaches, often linked to fuzzy sets. The green cluster, featuring smaller nodes, includes terms like "probabilistic linguistic term" and "consensus reaching". The yellow cluster, while moderately represented, includes terms like "occupational risk" which have some significance but are less prominent overall. The orange cluster is also notable, with the Fine–Kinney Method playing a central role, especially in risk analysis applications.

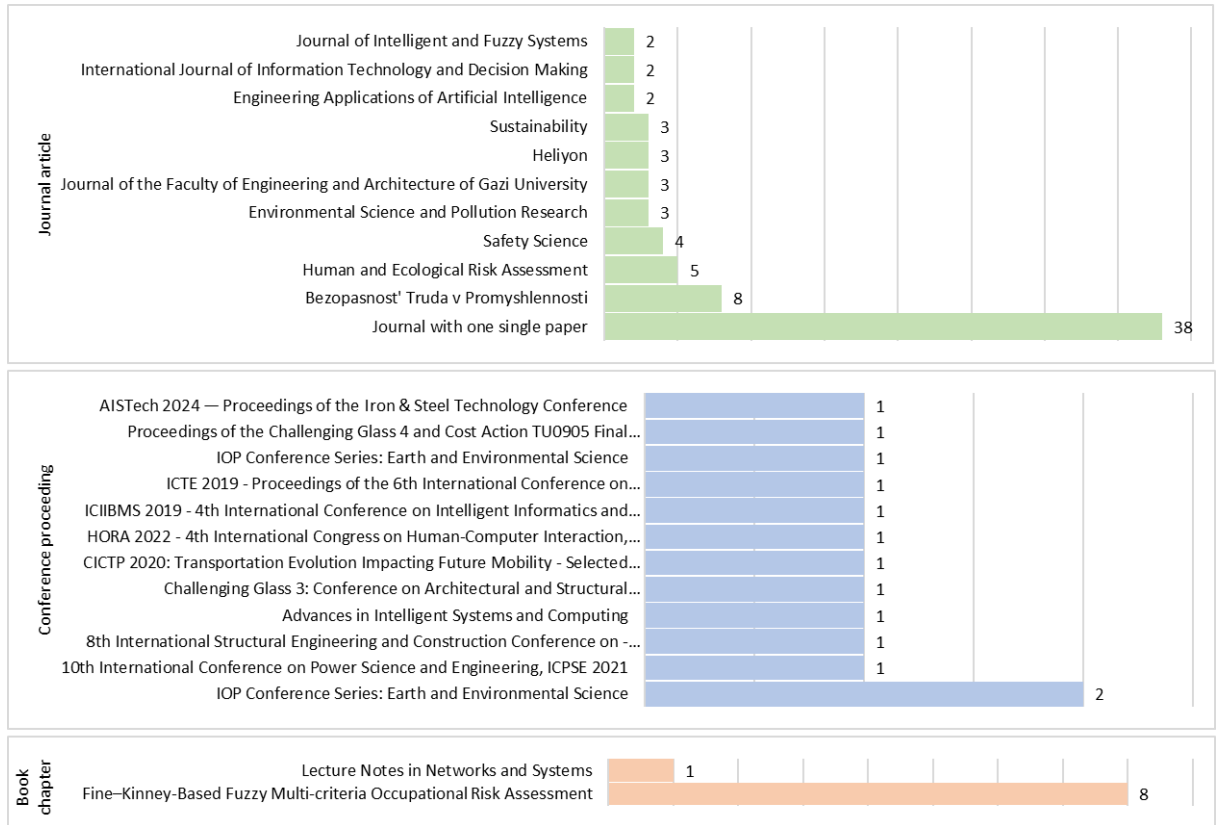


Figure 5. Journal-wise distribution of Fine–Kinney studies

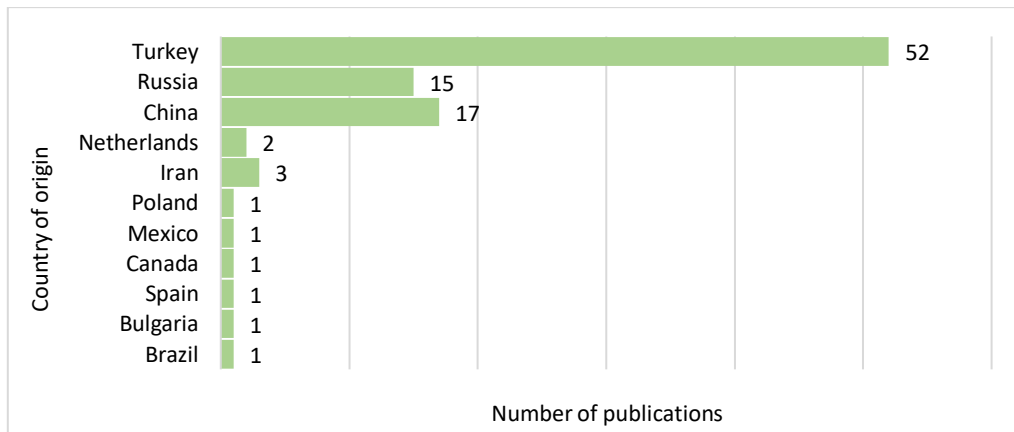


Figure 6. Distribution of Fine–Kinney studies by author's nationality

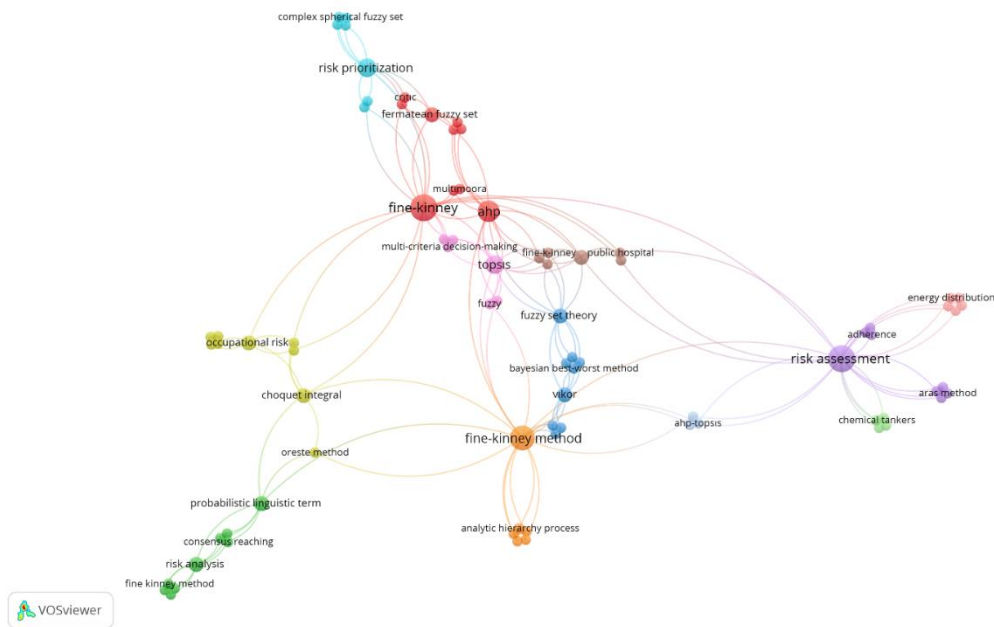


Figure 7. Bibliometric analysis of co-occurrence of author keywords

According to the analysis, the Fine–Kinney method has seen increased use in computer science and artificial intelligence in the past three years. The largest cluster in the bibliometric analysis includes MCDM methods, reflecting the method's evolution from a traditional risk assessment tool to a more interdisciplinary approach, particularly in AI applications. The analysis highlights that MCDM methods, fuzzy sets, and probabilistic linguistic terms are now frequently integrated to tackle more complex decision-making environments. Looking ahead, we anticipate a deeper integration of these methods, especially in addressing uncertainties and multi-criteria challenges in risk assessment, with a growing focus on AI-enabled decision systems and advanced computing environments where data complexity and uncertainty are prevalent.

(g) Subject areas: When the distribution of Fine–Kinney applications according to their subjects was examined, it was observed that most applications were made in engineering, environmental and computer science. Figure 8 is the subject area distribution chart obtained according to Scopus database information. These three fields are followed by medicine, energy, mathematics, and social sciences.

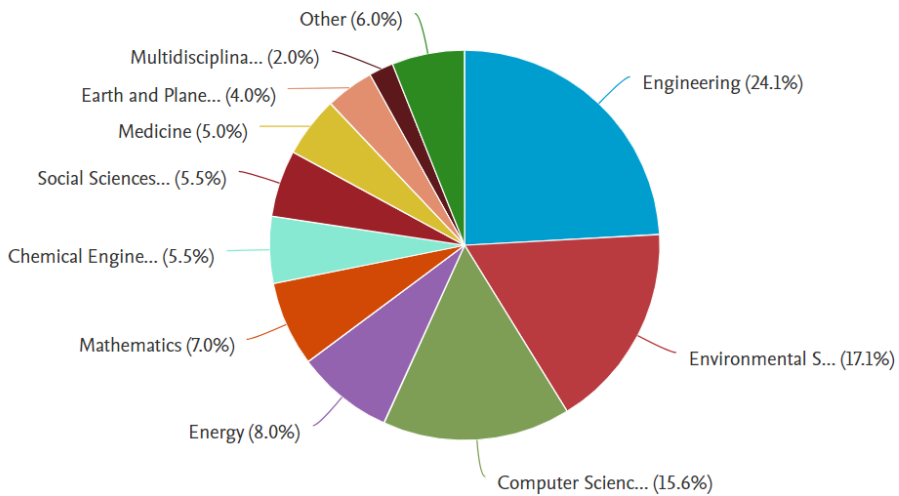


Figure 8. Distribution of Fine–Kinney studies by subject areas

4.2. Critical review results

Critical literature review is a common method for analyzing previous research, providing an overview of key ideas, arguments, or approaches related to a specific concept, theme, or theoretical perspective in the existing literature. This study employed a two-pronged classification to examine 95 Fine–Kinney occupational risk assessment studies as part of the critical review. The first category includes studies that exclusively use the traditional Fine–Kinney method, while the second focuses on hybrid studies that incorporate extensions of the Fine–Kinney method combined with additional techniques, methods, or concepts. Of the 95 articles, 27 utilize the method in its classical form, while 66 are hybrid applications. Additionally, two articles were brief review studies. The distribution of these studies is illustrated in Figure 9.

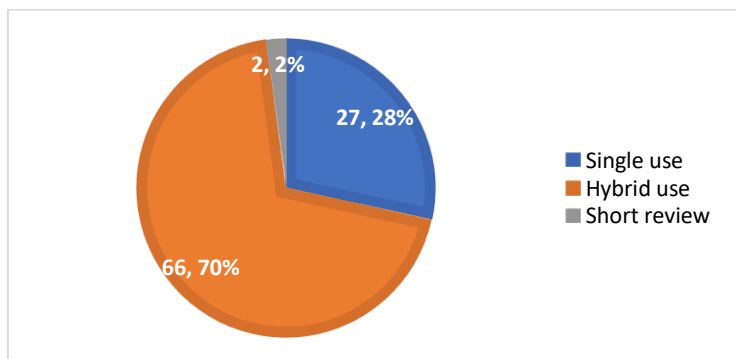


Figure 9. Distribution of Fine–Kinney studies based on the two-headed classification

(a) Stand-alone Fine—Kinney method (Single use): Most of the 27 single-use Fine—Kinney studies (n=15) are studies of Russian origin. In none of these studies can we talk about an effort to prevent a methodological limitation of the method. The focus of studies is often related to solving the risk assessment problem in an industry (Table 2). These sectors include mining (Kuleshov et al., 2023; Kuleshova and Pankov, 2020; Rudakov et al., 2021), energy (Gorlenko and Murzin, 2021; Kuleshova and Pankov, 2020; Karchina et al., 2022; Firsova and Pototskiy, 2023), manufacturing (Taranushina and Popova, 2019; Taranushina and Popova, 2021), construction (Simankina et al., 2020) and so on (Taranushina et al., 2020; Biktasheva & Vadulina, 2021; Kuleshov et al., 2023b; Kuznetsova and Mikryukova, 2023), where serious losses may occur due to work accidents and occupational diseases. In the field of mining, (Kuleshov et al., 2021) discuss coal mine risk analysis, while (Kuleshova and Pankov, 2020b), Pankov and Kuleshova (2020) and (Rudakov et al., 2021) focused on open-pit mining activities. The ultimate focus in single-use Fine—Kinney studies in energy is related to the risk analysis of a facility (usually an oil and gas facility) or the risk analysis of an activity in this facility. While Gorlenko and Murzin (2021) studied oil and gas production risk analysis, (Karchina et al., 2022) conducted a risk assessment for the electric and gas welder's workplace. On the other hand, studies are also carried out on occupational risk analyses of employees in gas facilities and heat-energy engineering enterprises (Kuleshova and Pankov, 2020b); (Firsova and Pototskiy, 2023). Similarly, the classical Fine—Kinney method is used for facilities where hazardous operations are carried out and where loading-unloading, material handling and storage systems are widely used (Taranushina and Popova, 2019, 2021). This study (Biktasheva & Vadulina, 2021) used Fine—Kinney for biological risk agents, unlike the hazardous sectors and activities mentioned above. Kuznetsova and Mikryukova (2023) tried to compare four classical risk assessment methods: Elmerly, Fine-Kinney, matrix, and checklist.

Table 2. Single-use Fine–Kinney studies with their novelty statements

| # | Study | Application area | Specific risk assessment problem | Novelty of the paper |
|----|--------------------------------|------------------|---|---|
| 1 | Kruijs (2012) | Manufacturing | Design of an all-glass roof | Risk assessment through the Fine–Kinney method for glass roof design |
| 2 | Ten Brincke and Nijssse (2014) | Construction | Safety and feasibility of an all-glass bridge with hotbended corrugated glass beams | Discussing the risk of lateral breakage by Fine–Kinney method |
| 3 | Özfirat et al., (2016) | Mining | Risk assessment in longwall mining | Use of Fine–Kinney occupational risk assessment method for longwall mining |
| 4 | Yapıcıoğlu (2018) | Environment | Environmental impact assessment | Usage of Fine–Kinney for environmental impact assessment for a meat processing industry |
| 5 | Cruz Netro et al., (2018) | Chemical | Supply chain risk assessment | Application of an adapted Fine–Kinney method for supply chain risk assessment |
| 6 | Taranushina and Popova (2019) | Manufacturing | Determining the level of occupational risk when organizing loading and unloading operations using bridge cranes with a lifting capacity of 20/5 t | Use of Fine–Kinney in occupational risk assessment at hazardous production facilities operating hoisting mechanisms |
| 7 | Simankina et al. (2020) | Construction | Monitoring the level of labor protection at construction sites in the agricultural sector | Suggesting a construction safety index with consideration of risk, which combines the Elmer system and the Fine–Kinney method |
| 8 | Pankov and Kuleshova (2020) | Mining | Occupational risk assessment in open-pit coal mining | Use of the Fine–Kinney matrix method and Guide R 2.2.1766-2003 together for open-pit coal mines |
| 9 | Taranushina et al. (2020) | N/A | N/A | To demonstrate the procedure for documentation execution of Fine–Kinney |
| 10 | Kuleshov et al. (2021) | Mining | Coal mining risk assessment | Describing the importance of assessing the severity of the consequences of an accident, as one of the components of occupational risk |
| 11 | Gorlenko and Murzin (2021) | Energy | Risk assessment in oil and gas production | Developing an integrated methodology (including the method of assessing the individual occupational risk level, the Fine–Kinney method, the method of scoring occupational risks, and the method of sociological survey of workers) for assessing occupational risks for oil and gas production companies |

| | | | | |
|-----------|----------------------------------|---------------|---|--|
| 12 | Rudakov et al. (2021) | Mining | Risk analysis in an open-pit mining operation | Tracing the evolution of risk-based thinking from quality management systems towards OSH management systems and demonstrating how an open-pit mining company can implement this approach |
| 13 | Taranushina and Popova (2021) | Manufacturing | Determining assessment levels of occupational risks at the mechanical engineering enterprises during lifting equipment operation | N/A |
| 14 | Biktaşeva and Vadulina (2021) | Environment | Assessing the biological risk factor | N/A |
| 15 | Boyacı et al. (2021) | Manufacturing | Risk assessment in an aluminum molding unit | Hazards prioritization via hesitant fuzzy linguistic term sets |
| 16 | Karchina et al. (2022) | Energy | Risk assessment for the workplace of an electric and gas welder | N/A |
| 17 | Kuleshov et al. (2023) | Aviation | Occupational health and safety | N/A |
| 18 | Firsova and Pototskiy (2023) | Energy | Occupational risk of personnel at a gas field facility | N/A |
| 19 | Kuznetsova and Mikryukova (2023) | N/A | N/A | Comparison of four classical risk assessment methods the Elmerly method, the Fine—Kinney method, the matrix method, and the checklist method |
| 20 | Tabak and Büyükakinci (2023) | Construction | Risk analysis of restoration works | Risk factors assessment in historical building restoration |
| 21 | Atacan and Düzbastılar (2023) | Maritime | Determination of risk perception in small-scale fishing and navigation | Applying Fine—Kinney in fishing operations |
| 22 | Kirova et al. (2024) | Manufacturing | Occupational risk assessment in cement manufacturing safety with Fine—Kinney | Applying Fine—Kinney for occupational safety risk assessment to exposure of respirable crystalline silica dust in cement manufacturing |
| 23 | Firat et al. (2023) | Maritime | Measurement of the degree of danger of the different tasks present in the current painting processes of large vessels | Usage of Fine—Kinney in risk prioritization for risk assessment in painting activities on large vessels |
| 24 | Ramirez-Peña et al. (2023) | Manufacturing | Risk assessment via Fine—Kinney in a firm serving maintenance of engineering life support systems of buildings and vehicle management | Assessment of the degree of occupational risk based on a risk-based approach |

Apart from Russia, several risk analysis studies have been carried out using the classical Fine—Kinney method in countries such as Turkey, the Netherlands, Mexico, Spain and Bulgaria. Studies such as glass roof design risk analysis (Kruijs, 2012), risk analysis for the safety and feasibility of an all-glass bridge with hot-spun corrugated glass beams (Ten Brincke and Nijse, 2014), risk assessment in longwall mining Özfirat et al. (2016), environmental impact assessment Yapıcıoğlu (2018), supply chain risk assessment (Cruz Netro et al., 2018), risk assessment in an aluminum molding unit Boyacı et al. (2021), risk analysis of restoration works (Tabak and Büyükkakinci, 2023) and determining risk perception in small-scale fishing and maritime (Atacan and Düzbastılar, 2023) can be given as examples.

All studies in the single-use class applied classical Fine—Kinney. Therefore, they have all the drawbacks of the method. The innovations contained in these studies are related to the field of application. It can be said that the method consists of studies designed to apply the method to risk analysis problems in mining, manufacturing, energy, construction, environment, and other sectors or to compare the results of a group of similar fundamental risk analysis methods such as L-matrix, checklist, elementary risk analysis.

(b) Extensions of Fine—Kinney with multiple techniques/methods/concepts (Hybrid use):

The majority of hybrid Fine—Kinney studies were conducted in manufacturing (n=14/66; 21%/100%) and construction (n=12/66; 18%/100%). A number of risk assessment studies, from marble to metal processing (Baç and Ekmekci, 2020; Gul and Ak, 2020), from chrome plating to water-based paint manufacturing (Gul et al., 2021; Hacibektasoglu et al., 2021), from weapons production to cement production (Gul et al., 2021), from automobile parts manufacturing to different types of large manufacturing facilities (Baç and Ekmekci, 2020; Kokangül et al., 2017; Korkmaz et al., 2016; Rui et al., 2019; Wang et al., 2022), have been carried out using one or more methods/concepts under the Fine-Kinney systematic (Table 3). Many of these studies on manufacturing risk assessment are unique in that fuzzy MCDM-based approaches are studied under the Fine-Kinney systematic for the first time. On the other hand, other than MCDM, there are also studies using ANFIS, which is based on the fuzzy inference system (Baç and Ekmekci, 2020b), and 5S, which is based on the improvement philosophy of cleanliness, tidiness, and organization of the workplace environment (Korkmaz et al., 2016).

The distribution of construction risk assessment studies is based on classical risk analysis techniques such as Delphi (Alipour-Bashary et al., 2021), FME (Karasan et al., 2018) A and L-matrix and ABC (Bilir and Gurcanli, 2015; Gurcanli et al., 2015), as well as FIS (Ilbahar et al., 2018; Karasan et al., 2018); and fuzzy MCDM based approaches (Alipour-Bashary et al., 2021; Ersoy et al., 2018; Seker, 2022; Wang, et al., 2023b; Wang, et al., 2023a; Yilmaz and Selim Ozcan, 2019). In both studies of Bilir and Gurcanli (2015) and (Gurcanli et al., 2015), Fine—Kinney has been applied in

activity-based risk assessment and safety cost estimation of the construction industry. Karasan et al. (2018) and Ilbahar et al. (2018) proposed two new risk assessment approaches called "Safety and Critical Effect Analysis (SECA)" enriched with Pythagorean fuzzy sets and "Pythagorean Fuzzy Proportional Risk Assessment (PFPR)" including Fine–Kinney, PFAHP, and FIS. Both studies used the risk parameters in the Fine-Kinney method, and the proposed new approach was constructed in this manner. When the studies on the subject are evaluated, construction sites, residential building construction projects, marble quarry block excavation processes, demolition projects, subway constructions, and natural gas pipeline constructions are the most important.

Manufacturing and construction, the two areas where hybrid Fine–Kinney studies are most frequently performed, are followed by energy and maritime.

Gul et al. (2018b) handled the problem of occupational risk assessment for the construction and operation period of wind turbines. They jointly used FAHP and FVIKOR in Fine–Kinney setting. Similarly, Bepary and Kabir (2022) studied the wind turbine risk assessment via a fuzzy-based risk model for wind turbine transportation, construction, operation, and maintenance. Aboubakar et al. (2021) and Efe and Efe (2023) proposed risk assessment models for hydro-power and natural gas pipeline projects, respectively. Dogan et al. (2022) performed a risk analysis study in a gas-filling facility by focusing on the action selection problem. Another study by Gul et al. (2022) aimed at prioritizing liquid fuel tank risk control measures by a BBWM-FVIKOR integration. They used BBWM for the first time in an occupational risk assessment problem and performed a control measures prioritization by an MCDM approach for the first time. Satıcı and Mete (2024) jointly applied the PFAHP and PFCOPRAS in Fine–Kinney concept for energy sector risk assessment.

In maritime-related studies, two important marine issues are handled most. The first is ballast tank maintenance (Gul et al., 2017; Tang et al., 2021; Wang et al., 2018). The second is ship collision (Yang et al., 2020; Yang et al., 2021). Yang et al. (2020) proposed the fuzzy rule-based Fine–Kinney method to analyze and evaluate the contribution values of the human risk factors in ship collision accidents. They compared with AHP and found correlations between relevant regulations' clarity degree and human factors' risk level. Unlike these, Elidolu et al. (2022) focused on gas-freeing operation risk assessment on tanker vessels via intuitionistic fuzzy sets, which helps better handle ambiguity and vagueness in expert judgment.

Table 3. Hybrid studies with methods used as an extension of the Fine—Kinney method

| # | Study | Techniques used | Study | Specific risk assessment problem |
|----|-------------------------------|---|---------------|---|
| 1 | Bilir and Gurcanli (2015) | L-Matrix method, ABC | Construction | Safety cost estimation for the construction industry |
| 2 | Gurcanli et al. (2015) | L-Matrix method, ABC | Construction | Activity-based risk assessment and safety cost estimation for residential building |
| 3 | Korkmaz et al. (2016) | 5S | Manufacturing | Occupational health and safety risk assessment for a gas meter manufacturing plant |
| 4 | Gul et al. (2017) | FAHP, FVIKOR | Maritime | Ballast tank maintenance |
| 5 | Kokangül et al. (2017) | AHP | Manufacturing | Hazard determination and risk assessment in a large manufacturing company |
| 6 | Wang et al. (2018) | Choquet integral, MULTIMOORA, RPRB-TFN | Maritime | Ballast tank maintenance |
| 7 | Gul and Celik (2018) | FRBS | Transport | Rail transportation systems risk assessment |
| 8 | Karasan et al. (2018) | FMEA, PFAHP, FIS | Construction | Safety and critical effect analysis for construction sites |
| 9 | Gul et al. (2018a) | FAHP, FVIKOR | Defense | Evaluation of risks in the arms industry |
| 10 | Ilbahar et al. (2018) | PFAHP, FIS | Construction | Pythagorean fuzzy proportional risk assessment |
| 11 | Gonen et al. (2018) | L-Matrix method | Healthcare | Modified matrix method for risk assessment |
| 12 | Gul et al. (2018b) | FAHP, FVIKOR | Energy | Occupational risk assessment approach for construction and operation period of wind |
| 13 | Xia et al. (2019) | FCEM | Manufacturing | Comprehensive evaluation of the health and safety of employees during the |
| 14 | Zhu et al. (2019) | Choquet integral, TODIM | Transport | Risk assessment of the electrical control device of the subway train door system |
| 15 | Yang et al. (2019) | FRBS | Maritime | Human error risk analysis of coastal water collision accidents |
| 16 | Yilmaz and Selim Ozcan (2019) | AHP | Construction | Risk analysis for lifting vehicles used in construction sites |
| 17 | Zhang et al. (2019) | FAHP | Transport | Airport operation situation risk assessment |
| 18 | Ersoy et al. (2019) | GRA | Construction | OHS-based risk analysis for block excavation process in a marble quarry |
| 19 | Gul and Ak (2020) | FBWM, FMAIRCA | Manufacturing | Risk assessment in a marble factory |
| 20 | Yang et al. (2020) | AHP, FRBS | Maritime | The human risk factor in ship collision accidents |
| 21 | Dagsuyu et al. (2020) | K-Means, Hierarchical clustering | Textile | Risk analysis of a workshop of a medium-sized textile company |
| 22 | Dagsuyu (2020) | PC, EOR | Environment | Process capability and risk assessment for air quality |
| 23 | Gul (2020) | FAHP, TODIM | Defense | Risk assessment in the gun and rifle assembly line of a weapon factory |
| 24 | Luo et al. (2020) | FAHP, random forest, ARIMA, Grey Markov | Transport | Hierarchical analysis of traffic situation |
| 25 | Baç and Ekmekci (2020) | ANFIS | Manufacturing | Assessing the employee psychosocial risks at a metal processing plant |
| 26 | Hacibektasoglu et al. (2021) | FSWARA, FCOPRAS, FVIKOR | Manufacturing | Risk assessment in water-based paint production |
| 27 | Baç and Ekmekçi (2021) | AHP | Manufacturing | Risk assessment in metal processing |
| 28 | Alipour-Bashary et al. (2021) | Delphi method, FFTA, FTOPSIS, FIS | Construction | Demolition project risk assessment |
| 29 | Aboubakar et al. (2021) | SWARA, TOPSIS | Energy | Hydro-power projects risk assessment |

| | | | | |
|----|---------------------------|---|----------------------------------|--|
| 30 | Can and Toktaş (2021) | KEMIRA-M, QFD | N/A | N/A |
| 31 | Gul et al. (2021) | IT2F-QUALIFLEX, PFVIKOR, IT2F-VIKOR, FBWM, FMAIRCA, HFMULTIMOORA, IF-TODIM, IT2F-TOPSIS, BWM, GIT2F-TODIM | Manufacturing, Defense, Maritime | Risk assessment in a chrome plating factory, in an oxidation and coloring unit in a gun manufacturing facility, in a cement plant, in the gun and rifle assembly line of a factory, Ballast tank maintenance |
| 32 | Derse (2021) | AHP, ELECTRE I, Goal programming | Disaster | Risk analysis in natural disasters for a region |
| 33 | Elidolu et al. (2022) | IF-TODIM | Maritime | Gas-freeing process risk analysis |
| 34 | Gökler et al. (2022) | ANFIS | Healthcare | Risk assessment in nursing homes |
| 35 | Seker (2022) | IVIF-AHP, IVIF-MULTIMOORA | Construction | Risk assessment in subway construction |
| 36 | Dogan et al. (2022) | AHP, TOPSIS, fuzzy logic | Energy | Risk analysis in a gas filling facility |
| 37 | Çalış Boyacı and Selim | Hesitant fuzzy set | Healthcare | Occupational health and safety risk assessment in operating rooms |
| 38 | Bepary and Kabir (2022) | FAHP, FTOPSIS | Energy | Wind turbine risk assessment |
| 39 | Wang et al. (2022) | WPA, ORESTE | Manufacturing | Risk assessment in automobile components manufacturing |
| 40 | Li et al. (2022) | Choquet integral, ORESTE, PLTS | N/A | N/A |
| 41 | Yakut et al. (2022) | DEMATEL, AHP, ANP, TOPSIS | N/A | N/A |
| 42 | Wang et al. (2022) | GLMS, MSMO | N/A | N/A |
| 43 | Güney and Kahraman (2022) | AHP | Environment | Risk assessment in environmental research laboratories |
| 44 | Moloudi et al. (2022) | AHP | Environment | Risk assessment for solid waste management |
| 45 | Gul et al. (2022) | BBWM, FVIKOR | Energy | Liquid fuel tank risk control measures prioritization |
| 46 | Tatar et al. (2023) | SF-AHP, SF-TOPSIS, SF-CODAS | Agriculture | Tea harvesting risk assessment |
| 47 | Wang et al. (2023) | CRADIS, Choquet integral | Construction | Natural gas pipeline construction project risk assessment |
| 48 | Wang et al. (2023) | FFMARCOS | Construction | Risk assessment in construction operations |
| 49 | Tosik et al. (2023) | AHP | Textile | Cotton fabric automatic screen-printing press occupational health and safety |
| 50 | Efe and Efe (2023) | QFD, VIKOR, q-ROFN | Energy | Natural gas pipeline project risk assessment |
| 51 | Satici and Mete (2024) | PFAHP, PFCOPRAS | Energy | Risk assessment for energy distribution and investment sector |
| 52 | Li et al. (2024) | Fuzzy sets, FIS | Construction | Occupational health risk assessment for Workers in different construction trades |
| 53 | Bayhun and Demirel (2024) | SFAHP, Extended CoCoSo | Maritime | Hazard identification and risk assessment for sustainable shipyard floating dock |
| 54 | Ayvaz et al. (2024) | FFAHP, FFWASPAS | Aquaculture | Occupational risk assessment in the aquaculture sector |
| 55 | Ak and Demir (2024) | IVSFTOPSIS | Transport | Occupational risk assessment for rail transit |
| 56 | Tang et al. (2024) | PLTs, CRP with dynamic SIN | Healthcare | Occupational risk assessment in hospital |
| 57 | Wang et al. (2024) | FCRADIS, IVSF Choquet integral, IVSF Entropy | Construction | Analyzing the occupational hazards in the metro construction process |
| 58 | Soltani et al. (2023) | FSWARA, FARAS | Environment | Risk assessment of firefighting job |

The remaining application domains that used a hybrid Fine–Kinney-based approach include transportation, agriculture, defense, disaster management, environment, healthcare, and textile. Gul and Celik (2018) and Zhu et al. (2019) produced two crucial risk assessment studies in rail transportation systems. While Gul and Celik (2018) combined Fine–Kinney method and a fuzzy rule-based expert system for Istanbul city's tram line risks, Zhu et al. (2019) assessed risks in the electrical control device of the subway train door system. Zhu et al. (2019) preferred Choquet integral and TODIM since these can effectively describe the interaction between risk criteria and reflect the psychological behaviors of decision makers. On the other hand, (Zhang et al., 2019) and (Luo et al., 2020) studied airport operation situation risk assessment and hierarchical analysis of traffic situation, respectively. In the agriculture domain, (Tatar et al., 2023b) employed a particular case study of Fine–Kinney method for tea harvesting risk assessment. Defense is another highlighted sector in which Fine–Kinney extensions exist (Gul et al., 2018, 2021; Gul and Ak, 2020). All these four studies performed risk analysis in a weapon factory's gun and rifle assembly line. (Derse, 2021) studied risk analysis during natural disasters for a region. The original contribution of Derse (2021)'s study lies in the usage of Fine–Kinney with the use of more than one method (AHP and ELECTRE) as an input and a mathematical model (goal programming). Regarding environmental issues, three studies are forefront (Dagsuyu, 2020; Güney and Kahraman, 2022; Moloudi et al., 2022). In Dagsuyu (2020), Fine–Kinney is used in severity analysis of air pollution. PC and EOR are merged into Fine–Kinney in process capability and risk assessment for air quality. Güney and Kahraman (2022) integrated AHP and Fine–Kinney for risk assessment for environmental research laboratories. Moloudi et al. (2022) contributed to solid waste management. They assessed the risk of health, safety, and environmental hazards using Fine–Kinney and environmental FMEA and prioritized risk hazards for implementing corrective actions by AHP. Musculoskeletal disorder risk assessment, nursing home, and operating room risk assessment are the main healthcare-related issues highlighted by scholars in the literature (Çalış Boyacı and Selim, 2022; Gökler et al., 2022; Gonen et al., 2018). Dagsuyu et al. (2020) and (Tosik et al., 2023) are scholars whose works are unique on contributing to textile risk assessment via Fine–Kinney concept. Tosik et al. (2023) assessed occupational health and safety risks of cotton fabric automatic screen-printing press. In some remaining works, there is no specific risk assessment problem which we cannot classify their application domain. Thus, we assigned them as “Non-applicable (N/A)” in our lists (Can and Toktaş, 2021; Li et al., 2022; Wang, Jiang, et al., 2022; Yakut et al., 2022). These studies generally include a contribution regarding methodological

aspects of fuzzy sets and Z numbers under Fine–Kinney. Novelities of hybrid studies with methods used as an extension of Fine–Kinney method are demonstrated in Table 4.

Table 4. Novelities of hybrid studies applied Fine–Kinney method

| # | Study | Novelty of the paper |
|----|-------------------------------|---|
| 1 | Bilir and Gurcanli (2015) | Applying of Fine–Kinney in safety cost estimation study of the construction industry |
| 2 | Gurcanli et al. (2015) | Usage of Fine–Kinney in an activity-based risk assessment and safety cost estimation study |
| 3 | Korkmaz et al. (2016) | Risk assessment through the quantitative Fine–Kinney method and the effect of adopting 5S workplace organization procedure |
| 4 | Gul et al. (2017) | Joint use of FAHP and FVIKOR in Fine–Kinney for maritime occupational risk assessment |
| 5 | Kokangül et al. (2017) | Proposing a new approximation for risk assessment using the AHP and Fine–Kinney |
| 6 | Wang et al. (2018) | Proposing a novel Fine–Kinney-based risk evaluation approach combining triangular fuzzy number, MULTIMOORA method and Choquet integral |
| 7 | Gul and Celik (2018) | Combination of Fine–Kinney method and a fuzzy rule-based expert system |
| 8 | Karasan et al. (2018) | Development of a new risk assessment method called Safety and Critical Effect Analysis (SECA) enriched with Pythagorean fuzzy sets |
| 9 | Gul et al. (2018a) | Joint use of FAHP and FVIKOR in Fine–Kinney-based risk assessment |
| 10 | Ilbahar et al. (2018) | Development of a new risk assessment method called Pythagorean Fuzzy Proportional Risk Assessment (PFPPRA), including Fine Kinney, Pythagorean fuzzy analytic hierarchy process, and a fuzzy inference system |
| 11 | Gonen et al. (2018) | Modified matrix method for risk assessment approach applied for the analysis of musculoskeletal disorders |
| 12 | Gul et al. (2018b) | Joint use of Fuzzy AHP and Fuzzy VIKOR in Fine–Kinney for wind turbine risk assessment |
| 13 | Xia et al. (2019) | To propose a perfect employee production evaluation system |
| 14 | Zhu et al. (2019) | *To effectively describe the interaction between risk criteria *To reflect psychological behaviors of decision makers |
| 15 | Yang et al. (2019) | Application of this method for the first time in the field of maritime affairs and can independently evaluate a single risk factor |
| 16 | Yilmaz and Selim Ozcan (2019) | Proposing a different risk priority ranking approach by merging Fine–Kinney and AHP |
| 17 | Zhang et al. (2019) | Development of an integrated model of situation value for airport operation situation |
| 18 | Ersoy et al. (2019) | Combination of Fine–Kinney and GRA methods in an occupational health and safety risk assessment *Development of the proposed approach for the marble industry |
| 19 | Gul and Ak (2020) | *Considering the severity of a hazard and its associated risk from the human health and environmental riskiness perspectives *Including BWM and MAIRCA under fuzzy set *Proposing the fuzzy rule-based Fine–Kinney method to analyze and evaluate the contribution values of the human risk factors in ship collision accidents |
| 20 | Yang et al. (2020) | *Making a comparison with AHP and finding correlations between relevant regulations clarity degree and human factors risk level |
| 21 | Dagsuyu et al. (2020) | Development of a new Fine–Kinney-based approach using clustering algorithms to define new classes to prioritize risks by overcoming the drawbacks of conventional Fine–Kinney method |

- 22 Dagsuyu (2020) *Use of Fine–Kinney in severity analysis of air pollution
*Merging PC and EOR into Fine–Kinney in process capability and risk assessment for air quality
- 23 Gul (2020) *Handling the occupational safety risk assessment problem in an integrated style of Fine–Kinney, FAHP and TODIM
- 24 Luo et al. (2020) Use of the combination of random forest, FAHP, and Fine–Kinney for hierarchical analysis of traffic situation
- 25 Baç and Ekmekci (2020) Joint use of Fine–Kinney and ANFIS for employee psychosocial risk assessment
- 26 Hacibektasoglu et al. (2021) Proposing a novel approach using SWARA and COPRAS based on fuzzy sets to perform a Fine–Kinney risk analysis
- 27 Baç and Ekmekçi (2021) N/A
- 28 Alipour-Bashary et al. (2021) Providing a comprehensive framework (a combination of the Delphi, Fine–Kinney, fuzzy fault tree analysis, TOPSIS, and fuzzy inference system) for risk assessment and determination of building demolition safety index
- 29 Aboubakar et al. (2021) Assessment of the risk factors and categories that are crucial to hydro-power projects and rank them according to their effect on project success
- 30 Can and Toktaş (2021) N/A
- 31 Gul et al. (2021) Adaptation of the IT2F- QUALIFLEX to the Fine– Kinney occupational health and safety risk assessment; Usage of Pythagorean FVIKOR in a Fine–Kinney-based risk assessment study; A solid approach to the occupational health and safety risk assessment with interval type-2 fuzzy VIKOR; Joint usage of F-BWM and F-MAIRCA in a Fine–Kinney-based risk assessment study; Development of a Fine–Kinney-based approach using HFMULTIMOORA for the first time; Development of a Fine–Kinney-based approach using intuitionistic fuzzy TODIM for the first time; The Fine–Kinney concept is merged with the interval type-2 fuzzy set concept and TOPSIS for the first time through the literature.
- 32 Tang et al. (2021) Proposing a hybrid Fine–Kinney based on the generalized TODIM method by making the evaluation process more objective and credible through type-2 fuzzy numbers and aiding determination of the objective importance weight of each risk parameter.
- 33 Derse (2021) Proposing a new Fine–Kinney using AHP, ELECTRE and goal programming
- 34 Elidolu et al. (2022) Dealing with the risk assessment process of gas freeing operation on tanker vessels via intuitionistic fuzzy sets helps better handle ambiguity and vagueness in expert judgment
- 35 Gökler et al. (2022) Integration of Fine–Kinney and ANFIS
- 36 Seker (2022) Proposing a novel hybrid approach, which includes Fine–Kinney, AHP and MULTIMOORA under interval-valued intuitionistic fuzzy to handle uncertainty in the risk evaluation
- 37 Dogan et al. (2022) Handling of the action selection problem
- 38 Çalış Boyacı and Selim (2022) Combining Fine–Kinney and multi-criteria hesitant fuzzy linguistic terms set in an occupational risk assessment problem
- 39 Bepary and Kabir (2022) Implementation of a fuzzy-based risk evaluation method for the transportation, construction, operation, and maintenance of wind turbines
- 40 Wang et al. (2022) Proposing an improved Fine–Kinney model for OHS risk assessment integrating the weighted power average operator, ORESTE and cumulative prospect theory
- 41 Li et al. (2022) N/A
- 42 Yakut et al. (2022) Suggesting a Z-number-based risk assessment framework
- 43 Wang et al. (2022) Exploring occupational risk assessment and prioritization problems considering the interactive relationships between multiple risk parameters in inter- and intra-uncertainty environments

| | | |
|----|---------------------------|---|
| 44 | Güney and Kahraman (2022) | Risk assessment for environmental research laboratories using AHP and Fine–Kinney integration |
| 45 | Moloudi et al. (2022) | Assessment of the risk of HSE hazards using Fine–Kinney and environmental FMEA and risk hazards prioritization for implementing corrective actions by AHP |
| 46 | Gul et al. (2022) | BBWM-FVIKOR integration; usage of BBWM for the first time in an occupational risk assessment problem and performing a control measures prioritization by an MCDM approach for the first time |
| 47 | Tatar et al. (2023) | Integrating Fine–Kinney and spherical fuzzy AHP-TOPSIS |
| 48 | Wang et al. (2023) | Uncover the impact of interactive risk factors with the usage of Choquet integral |
| 49 | Wang et al. (2023) | Use of Fermatean fuzzy data in the risk ranking procedure considering the prioritization degrees and bounded rational behavior of decision-makers |
| 50 | Tosik et al. (2023) | Joint usage of the Ishikawa diagram (used to determine the risks), and AHP |
| 51 | Efe and Efe (2023) | Integration of Fine–Kinney, q-ROFN-based QFD, VIKOR methods in a risk assessment study |
| 52 | Soltani et al. (2023) | Developing an integrated fuzzy SWARA-ARAS framework for firefighting job risk assessment |
| 53 | Soltani et al. (2023) | Proposing a decomposed fuzzy set-based Fine–Kinney method in a risk assessment problem for the first time in the literature |
| 54 | Li et al. (2024) | Usage of Fine–Kinney fuzzy-based occupational health risk assessment for Workers in different construction trades |
| 55 | Bayhun and Demirel (2024) | Demonstrating a practical risk assessment model for shipyard floating dock operations |
| 56 | Ayvaz et al. (2024) | Usage of FFAHP and FFWASPAS under Fine–Kinney concept |
| 57 | Ak and Demir (2024) | Usage of IVSFTOPSIS under Fine–Kinney concept in a rail transit network risk assessment |
| 58 | Tang et al. (2024) | Development a hybrid generalized TODIM approach in the Fine–Kinney framework, integrating consensus reaching process (CRP) with dynamic social influence network (SIN) and probabilistic linguistic terms |
| 59 | Wang et al. (2024) | Developing an integrated CRADIS method-based Fine–Kinney framework |
| 60 | Satici and Mete (2024) | Joint use of PFAHP and PFCOPRAS in Fine–Kinney for energy sector risk assessment |

4.2.1. Risk factor weighting methods

The classic Fine–Kinney method defines and numerically evaluates risk based on three basic risk factors. These are probability, exposure and consequence, as detailed in Section 2.1. In this literature review, 88% of the studies use this trio as risk parameters (Table 5). Exceptionally, in some studies, some different parameters were used. One is "cost of the hazard" (Boyaci et al. 2021). Another one is about the detectability of the hazard. This parameter was added to the original occupational risk assessment study proposed by Karasan et al. (2018). Although this is a factor of FMEA, "detection" is the fourth parameter in their proposed new Fine–Kinney-based model. Moloudi et al. (2022) took the risk assessment study to a different perspective by proposing a model with miscellaneous factors (a total of six factors). These parameters are probability, consequence, simultaneous health and safety effects, feasibility, effectiveness, and cost of corrective actions. The risk parameter, an important element of occupational risk

assessment studies, shows how we define the risk as a component of such parameters. At the same time, a score is made for each hazard under these defined parameters. We cannot discuss weighting in classical methods like Fine–Kinney. However, in Fine–Kinney based risk assessment studies combined with MCDM, fuzzy logic, ANFIS and some other methods, concepts and techniques, a weight value is assigned for these parameters.

Table 5. Risk factors used in the reviewed studies

| Risk factors (parameters) of Fine–Kinney | No. of study | Percent age |
|--|---------------------|--------------------|
| probability, exposure, consequence | 84 | 88% |
| probability, consequence, simultaneous HSE effects, feasibility, effectiveness, cost of corrective actions | 1 | 1% |
| probability, exposure, consequence, cost | 1 | 1% |
| probability, exposure, consequence, detection | 1 | 1% |
| severity, intensity of the affected person | 1 | 1% |
| probability, exposure, consequence, cost, preventability and personal protective use | 1 | 1% |
| probability, exposure, consequence and number of people at risk | 1 | 1% |
| N/A | 5 | 5% |

It is also possible to read from the analysis results that pairwise comparison-based MCDM techniques mostly lead to determining these values. Table 6 shows the distribution of risk parameter weighting methods used in the 95 studies reviewed. Among 95 studies, 52 studies have not contained any weight information. Therefore, Table 6 is for the remaining 43 studies. FAHP (7 studies), AHP (6 studies) and PFAHP (3 studies) are most frequently preferred in weighting Fine–Kinney risk parameters. AHP is an MCDM technique based on pairwise comparison logic proposed by (Saaty, 1980), It has been applied to many problems (Emrouznejad and Marra, 2017; Ho, 2008; Ishizaka and Labib, 2011; Subramanian and Ramanathan, 2012). In the occupational risk assessment problem, each risk parameter is considered a "criterion" (an important component when solving decision analysis problems with MCDM is the existence of criteria). These are pair wisely evaluated by using a linguistic scale with decision-makers' help. Here, one of the biggest handicaps AHP and its derivatives face is the decrease in the decision maker's ability to make consistent evaluations as the number of criteria increases. However, since three risk parameters (probability, exposure, consequence) are generally taken into account in the Fine–Kinney method (observed in Table 5), the problem is easy and fast to solve by using AHP and its extensions.

Table 6. Risk factor weighting methods used in the reviewed studies

| Risk parameter weighting method | No. of studies | Related reference |
|---|-----------------------|--|
| FAHP | 7 | Bepary and Kabir (2022); Gul (2020); Luo et al. (2020); Zhang et al. (2019); Gul et al. (2018a); Gul et al. (2018b); Gul et al. (2017) Tosik et al. (2023); Dogan et al. (2022); |
| AHP | 6 | Güney and Kahraman (2022); Moloudi et al. (2022); Baç and Ekmekçi (2021); Yilmaz and Selim Ozcan (2019) |
| PFAHP | 3 | Karasan et al. (2018); Ilbahar et al. (2018); Satici and Mete (2024) |
| HFLTS | 2 | Çalış Boyacı and Selim (2022); Boyaci et al. (2021) |
| FBWM | 2 | Gul et al. (2021); Gul and Ak (2020) |
| FSWARA | 2 | Hacibektasoglu et al. (2021); Soltani et al. (2023) |
| SFAHP | 2 | Tatar et al. (2023); Bayhun and Demirel (2024) |
| ANFIS | 1 | Gökler et al. (2022) |
| BWM (crisp) | 1 | Tang et al. (2021) |
| Choquet integral | 1 | Wang et al. (2023) |
| Direct given benefiting from the literature (Different weights) | 1 | Gul et al. (2021) |
| Fermatean fuzzy PWA operator | 1 | Wang et al. (2023) |
| FIS | 1 | Alipour-Bashary et al. (2021) |
| HFMULTIMOORA | 1 | Gul et al. (2021) |
| IT2FQUALIFLEX | 1 | Gul et al. (2021) |
| IVIFAHP | 1 | Seker (2022) |
| IFTODIM | 1 | Elidolu et al. (2022) |
| IFWAO | 1 | Gul et al. (2021) |
| q-ROFN | 1 | Efe and Efe (2023) |
| RPRBTFN ranking method integrated with Choquet integral | 1 | Wang et al. (2018) |
| Similarity degree | 1 | Zhu et al. (2019) |
| SWARA | 1 | Aboubakar et al. (2021) |
| WPAO | 1 | Wang et al. (2022) |
| FFAHP | 1 | Ayvaz et al. (2024) |
| Z-number based AHP, Z-number based ANP | 1 | Yakut et al. (2022) |
| IVSF Entropy | 1 | Wang et al. (2024) |

When the problem of determining risk parameter weights is straightforward, simple and uncomplicated, the results obtained are often tested with a sensitivity analysis. For example, due to a Fine–Kinney study, the weights of probability, exposure and consequence parameters were found to be 0.310, 0.496 and 0.194, respectively (Bepary and Kabir, 2022). Weights were obtained with FAHP. However, a sensitivity study is carried out to observe better how sensitive each hazard and associated risk is to the change in the importance of weight of these parameters. Because it is important to determine within what limits the weight values, do not cause a change in the risk ranking. How the weight value of each parameter varies between 0 and 1 is related to the facility, process or sectors that are analyzed and evaluated. In all studies conducted in literature, the tendency of these importance values is not in the same direction. For example, in the study by Bepary and Kabir (2022) that analyzed the risks in the operation, construction, transportation and maintenance processes of wind turbines, the most important parameter was “exposure”, while in another study by Gul et al. (2018a), the most important parameter was “consequence”.

Besides AHP and its derivatives, another MCDM method that works according to the pairwise comparison logic is BWM. AHP method cannot deal with complex and inconsistent decision-making processes. Therefore, literature needed a method that required fewer pairwise comparisons and provided more time for the decision makers (Rezaei, 2015). contributed to the literature by introducing the BWM to fill this gap. Since introducing the BWM to literature, it has attracted the attention of many academicians, scholars, and practitioners and has employed a wide range of topics. One of these topics is occupational health and safety risk assessment. BWM and FBWM have been used in Fine–Kinney risk assessment studies (Gul et al. 2021; Tang et al. 2021; Gul and Ak, 2020). These limited studies clarify that an MCDM method that determines the weights, thanks to an optimization model with a strong mathematical background, provides great convenience in determining the real risk rankings and classes for Fine-Kinney studies.

Çalış Boyacı and Selim (2022) and Boyacı et al. (2021) employed another risk parameter weighting method called “multi-criteria HFLTS method”. HFLTS reduces the difficulty decision makers have in defining linguistic terms and provides flexibility in their evaluations. These sets enable decision maker experts using hesitation with suitable linguistic expressions. With these features, they contribute to the literature in risk assessment.

Apart from these commonly used methods (AHP and its derivatives, BWM and its derivatives, HFLTS), there are also methods with a frequency value of only 1 (that is, they have been used in just one study). These are generally methods in which fuzzy logic is integrated with MCDM

methods (Wang et al. 2023; Wang et al. 2023; Hacibektasoglu et al. 2021; Gul et al. 2021; Seker, 2022; Elidolu et al. 2022; Efe and Efe, 2023; Wang et al. 2018; Zhu et al. 2019; Tatar et al. 2023; Aboubakar et al. 2021; Wang et al. 2022), fuzzy inference system based methods (Gökler et al. 2022; Alipour-Bashary et al. 2021), and Z-number and MCDM are integrated methods (Yakut et al., 2022). Wang et al. (2023) developed a risk information fusion method based on the WPAO, which is helpful for Fine–Kinney. Classical Fine–Kinney model rarely considers the prioritization degrees of decision makers. However, with the aid of the proposed WPAO, the prioritization relationships among information in the aggregation process can be reflected easily. Another WPAO-based aggregation method is used by Wang et al. (2022). It can reduce the deviation of risk rating information in the information fusion procedure. Also, the optimization model with group consensus degree can provide an objective weight vector for each decision-maker. This can finally support an objective and reliable group risk rating matrix. Similarly, in Elidolu et al. (2022), the weights of Fine–Kinney risk parameters are calculated by using the IFWAO. Hacibektasoglu et al. (2021) applied a hybrid methodology in which the risk parameter weighting part of their study uses FSWARA. Due to its requirement of considerably lower pairwise comparisons compared to AHP for the same number of criteria and its simplicity against AHP, they suggested weighting Fine–Kinney risk parameters via FSAWARA.

4.2.2. Risk assessment methods

Normally, with Fine–Kinney, risk assessment is carried out by a team of different levels of expertise within/outside the facility. Fine–Kinney team members' evaluations in group risk assessment are often fuzzy, imprecise, vague, and hesitant due to time pressure, lack of information, information loss, and limited human judgment processing capabilities. Therefore, several fuzzy theories and methods were used in the studies examined in this review paper. Table 7 shows how the risks are assessed for 95 studies with their related references.

The question of how risks are evaluated here is essentially related to the situation as follows: In classic Fine–Kinney, there is a rating/value for each parameter as presented in Table 1. These are crisp and constant values. As a result, a risk priority value is calculated (just like in FMEA) and the risk status is revealed. In risk assessment, fuzzy logic and its extensions are often used to make the subjective evaluations of decision makers more sensitive and to operate the decision-making mechanism in cases with insufficient data. In Table 6, although almost half of the studies were evaluated with numerical values (approximately 45% and 43/95 studies), many studies used fuzzy sets and their extensions (approximately 35% and 33 studies). Studies in which it is not known how risks are evaluated constitute 20% of all studies and are 19 in number. In particular, triangular

fuzzy numbers are the preferred fuzzy set extension to evaluate risks in the studies examined. This is followed by Pythagorean fuzzy numbers and interval type-2 fuzzy numbers. As known, type-2 fuzzy set is a classical fuzzy set in which a single membership function value is considered uncertain. Pythagorean fuzzy set is a type that has both membership and non-membership functions but has a larger decision space than the intuitionistic fuzzy set. Therefore, it has been preferred because it is relatively new and better reflects uncertain situations in occupational risk assessment problems.

Table 7. Methods used to assess the risks

| How are the hazards assessed? | No. of studies | Related reference |
|-------------------------------|----------------|---|
| Numerical values | 43 | Firsova and Pototskiy (2023); Kuznetsova and Mikryukova (2023); Tosik et al. (2023); Elidolu et al. (2022); Gökler et al. (2022); Dogan et al. (2022); Gul et al. (2022); Çalış Boyacı and Selim (2022); Karchina et al. (2022); Aboubakar et al. (2021); Taranushina and Popova (2021); Biktasheva and Vadulina (2021); Simankina et al. (2020); Dagsuyu et al. (2020); Dagsuyu (2020); Gul (2020); Luo et al. (2020); Pankov and Kuleshova (2020); Kuleshova and Pankov (2020); Baç and Ekmekci (2020); Taranushina et al. (2020); Xia et al. (2019); Yilmaz and Selim Ozcan (2019); Zhang et al. (2019); Taranushina and Popova (2019); Ersoy et al. (2019); Yapıcıoğlu (2018); Gonen et al. (2018); Cruz Netto et al. (2018); Kokangül et al. (2017); Korkmaz et al. (2016); Özfirat et al. (2016); Ten Brincke and Nijse (2014); Kruijs (2012); Derse (2021); Atacan and Duzbastilar (2023); Bilir and Gurcanli (2015); Gurcanli et al. (2015); Cardoso et al. (2024); Kirova et al. (2024); Fırat et al. (2023); Ramirez-Peña et al. (2023); Gerasimenko (2023) |
| N/A | 19 | Kuleshov et al. (2023); Tabak and Büyükakinci (2023); Taş and Akay (2022); Li et al. (2022); Wang et al. (2022); Güney and Kahraman (2022); Moloudi et al. (2022); Kuleshov et al. (2021); Baç and Ekmekçi (2021); Alipour-Bashary et al. (2021); Gorlenko and Murzin (2021); Rudakov et al. (2021); Boyacı et al. (2021); Can and Toktaş (2021); Gul et al. (2021); Li et al. (2024); Tang et al. (2024) |
| Triangular fuzzy numbers | 12 | Bepary and Kabir (2022); Hacibektasoglu et al. (2021); Gul et al. (2021); Gul and Ak (2020); Yang et al. (2020); Yang et al. (2019); Wang et al. (2018); Gul and Celik (2018); Gul et al. (2018a); Gul et al. (2018b); Gul et al. (2017); Soltani et al. (2023) |
| Spherical fuzzy numbers | 5 | Tatar et al. (2023); Wang et al. (2023); Ak and Demir (2024); Bayhun and Demirel (2024); Wang et al. (2024) |
| Pythagorean fuzzy numbers | 4 | Gul et al. (2021); Karasan et al. (2018); Ilbahar et al. (2018); Satici and Mete (2023) |

| | | |
|-----------------------------------|---|---|
| Interval type-2 fuzzy numbers | 3 | Gul et al. (2021); Tang et al. (2021) |
| Interval 2-tuple linguistic terms | 2 | Wang et al. (2022); Zhu et al. (2019) |
| Intuitionistic fuzzy numbers | 2 | Seker (2022); Gul et al. (2021) |
| Fermatean fuzzy numbers | 2 | Wang et al. (2023); Ayvaz et al. (2024) |
| Q-rung orthopair fuzzy numbers | 1 | Efe and Efe (2023) |
| Decomposed fuzzy numbers | 1 | Cebi and Kaliyaperuma (2023) |
| Z numbers | 1 | Yakut et al. (2022) |

Another preferred fuzzy extension is “spherical fuzzy set”, which first appeared in the literature in 2018. Unlike Pythagorean fuzzy set, it provides a wider range of preferences for decision makers to assign membership, non-membership, and hesitation degrees. Tatar et al. (2023) and Wang et al. (2023) applied these set to their occupational risk assessment problems. In Tatar et al. (2023)’s study, three parameters of Fine–Kinney have been weighted via SFAHP. Then, it has been integrated with SFTOPSIS to rank risks that emerged in tea harvesting workers for work-related musculoskeletal disorders. On the other side, Wang et al. (2023) used spherical fuzzy numbers within CRADIS method to rank occupational risks. Experts’ evaluations under complex spherical fuzzy numbers have been aggregated with PWAO. This type of fuzzy numbers considers the influence of experts’ priority degrees when compared to previously mentioned fuzzy extensions. Wang et al. (2023), Efe and Efe (2023) and Yakut et al. (2022) use Fermatean fuzzy numbers, Q-rung orthopair fuzzy numbers and Z numbers in assessing hazards, respectively. Wang et al. (2023) used Fermatean fuzzy PWAO to fuse individual DM’s risk scoring information in the Fine–Kinney risk assessment model. Fermatean fuzzy numbers have a broader coverage of uncertain information. They can avoid loss of knowledge. This study has also merged prospect theory with MARCOS under Fine–Kinney concept. Traditional MARCOS MCDM models can suggest a compositive risk priority order but cannot handle the decision makers’ psychological characteristics. Therefore, Wang et al. (2023)’s study can overcome such the drawbacks of classical risk assessment methods and offer an innovative model instead. Efe and Efe (2023) employed q-rung orthopair fuzzy numbers in a natural gas pipeline project risk assessment. q-ROFNs cover more information than intuitionistic and Pythagorean fuzzy numbers. They collected the experts’ judgments from linguistic terms in q-ROFNs and transformed and aggregated them by an q-rung orthopair fuzzy-based aggregating operator. Such an integrated method under Fine–Kinney can

improve the deficiencies of classical Fine–Kinney. Finally, Z-numbers have also been studied within the scope of occupational risk assessment via Fine–Kinney (Yakut et al., 2022).

5. Discussion

In this section, in the light of the inferences obtained from the bibliometric analysis and critical literature review conducted so far, it is discussed what the open problems are, what the solutions that can be used to address these problems (not yet found in literature), what the potential improvements and opportunities for future work are.

1. Successful applications across various sectors: The Fine–Kinney method has demonstrated successful applications across diverse sectors such as agriculture, aviation, chemical, construction, defense, disaster management, energy, environment, healthcare, maritime, mining, textile, and transportation. Despite this diversity, certain sectors, including agriculture and aviation, remain underexplored, presenting opportunities for future research.
2. Dramatic increase in research post-2012: There has been a notable rise in studies using the Fine–Kinney method since 2012, reflecting a growing interest in improving occupational risk assessment practices. This trend highlights the method's evolving relevance in academic and industrial research.
3. Hybrid approaches dominate: A significant number of studies combine the Fine–Kinney method with the AHP, particularly for risk parameter weighting. While this combination is widespread, there is potential for more sophisticated integrations, such as fuzzy logic extensions or newer MCDM techniques.
4. Limited risk parameters: The majority of studies rely on the traditional three risk parameters—probability, exposure, and consequence. Expanding these parameters or introducing sub-parameters could enhance the accuracy of risk assessments. Furthermore, dynamic conditions, such as future changes in work environments, are often neglected in current studies. Addressing these uncertainties with new methodologies, like stratified MCDM, is a promising area for future research.
5. Need for advanced fuzzy set techniques: While some studies have incorporated fuzzy logic, there is a gap in applying more advanced fuzzy set techniques such as trapezoidal fuzzy sets, hesitant fuzzy sets, picture fuzzy sets, circular intuitionistic fuzzy sets and decomposed fuzzy sets. The integration of these methods could provide greater flexibility and precision in dealing with uncertainty in risk assessments.
6. Expert selection and group decision-making: The selection of experts for Fine–Kinney assessments remain an underexplored topic. Future studies could benefit from focusing on

expert selection processes, incorporating group decision-making techniques, and considering the degree of hesitation or consensus among experts. This could improve the reliability and robustness of the risk assessments.

7. Opportunities for innovation: Several areas offer potential for future innovations, including:

- Expanding Fine–Kinney into underexplored sectors such as disaster management, agriculture, and aviation.
- Enhancing the methodology with advanced MCDM techniques and fuzzy set extensions.
- Accounting for dynamic future conditions that may alter the importance of risk parameters. For example, stratified MCDM (Asadabadi, 2018), which emerged by integrating the stratification philosophy with MCDM, can be used to reflect this dynamic state in a proposed approach.
- Developing new tools, such as Bayesian networks, to reveal causal relationships between risk factors.
- A proactive model can be created that uses not only historical data or expert opinions but also real-time data more effectively. Thus, many work accidents can be prevented before they occur.
- By focusing more on data collection through Internet of Things and sensors and using predetermined models, instant analyses can be made.
- By transferring the obtained risk analysis results to managers and employees using different teaching methods, risk awareness and the effectiveness of the obtained results can be increased.
- By transferring the obtained analysis results to virtual reality and simulation tools, awareness and risk prediction for employees can be increased.

By addressing these gaps, researchers can significantly advance the Fine–Kinney method, making it more adaptable to modern industrial challenges and more accurate in occupational health and safety applications.

It is seen that the applications of the Fine–Kinney occupational risk assessment method are very few and limited in fields such as agriculture, aviation, chemistry, disaster management and textile. It is thought that innovative studies in these areas will contribute to the field.

6. Conclusion

This study focuses on a bibliometric analysis and a critical literature review of studies using the Fine–Kinney method, an important risk assessment tool used in the industry and by scholars.

Studies have been categorized based on whether they used the Fine–Kinney method as a single or hybrid style. The risk factors used in the reviewed studies, risk factor weighting methods and risk assessment methods, usage of fuzzy sets, fuzzy extension type, and shortcomings of Fine–Kinney are included. In addition, many bibliometric elements such as the trend of the studies, the most popular MCDM approach for Fine–Kinney, the most cited research, the outlets where the studies were published, the country of origin and subject areas of the studies have also been examined and interpreted with graphics.

In the first stage, keywords were determined and used in order to comprehensively scan all studies in the literature related to the Fine–Kinney method. Duplicate studies were eliminated from the studies obtained. In the second stage, the publication years of these studies, study types, MCDM methods used, the most influential studies, the nationalities of the researchers, the fields of publication and the use of “Fine–Kinney and other keywords” were investigated in order to determine future trends. In the third stage, a critical literature review was conducted and the extensions of the Fine–Kinney method were determined. Thanks to these three stages, studies related to the Fine–Kinney method were comprehensively categorized, and a general framework was created on the subject. This process provided an opportunity for those who conduct research on the subject to identify current research gaps and also guided them in predicting future trends.

After an in-depth analysis of the pool of studies, several findings and inferences have been identified as follows:

- (1) It has been observed that the Fine–Kinney method has been successfully applied in different fields such as agriculture, aviation, chemical, construction, defense, disaster management, energy, environment, healthcare, manufacturing, maritime, mining, textile and transportation.
- (2) Studies using Fine–Kinney have increased dramatically since 2012.
- (3) The Fine–Kinney method has been mostly used together with the AHP method. Generally, using AHP in these studies is to weigh three risk parameters of Fine–Kinney or as a benchmarking method instead of Fine–Kinney.
- (4) The largest number of studies are carried out in Türkiye. According to the results of Pareto analysis, the keywords in the studies are risk assessment, occupational health and safety, and “Fine-Kinney”, which is the method's name.
- (5) Three risk parameters of probability, exposure, and consequence have been considered in the vast majority of studies. FAHP is the most preferred in determining risk parameter weighting.

Although numerical values are most preferred in assessing risks, fuzzy numbers have also been widely used. Studies using triangular fuzzy numbers take the lead among fuzzy set-based studies.

When all studies are examined holistically, they either have a field innovation in terms of its applicability to a new field or sector or an innovation in terms of the applied methodology (which is mostly due to an improvement in the fuzzy set part of the preferred fuzzy MCDM approach or an improvement resulting from the selection of the MCDM method appropriate to the problem). We see that these two innovative paths are progressing head-to-head. However, it is thought that the topics that can be considered as opportunities for future Fine–Kinney studies may be as follows:

- (1) Evolution of unapplied areas and MCDM techniques suitable for the problem structure have not been applied before into new approaches under Fine–Kinney.
- (2) Improving the number and quality of Fine–Kinney parameters
- (3) Taking into account the possibility that the weights of Fine–Kinney risk parameters may change under possible conditions that may be encountered in the future when establishing the model and injecting this stratified structure into the risk assessment problem.
- (4) Developing original approaches by combining new and original fuzzy set extensions, techniques capable of revealing cause and effect relationships between parameters such as Bayesian network, and original techniques used in problem-solving under Fine–Kinney.

The Fine–Kinney method has attracted increasing interest in the field of risk analysis and management. Future studies could explore more complex and sensitive applications. Possible future trends include: 1) Integration with probabilistic models to obtain more realistic results in environments with uncertain and dynamic risk factors. 2) Integration with artificial intelligence and big data analysis to develop holistic and sensitive models that address the limitations of classical Fine–Kinney. 3) Integration with different fuzzy sets and MCDM to incorporate expert opinions into the model in a more sensitive manner. It is anticipated that Fine–Kinney will have broader theoretical and practical applications in the future.

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