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Rethinking Risk Matrices: A Scoping Review of Probability Consequence Diagrams and Decision Framework for Diagram Selection

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Risk Analysis

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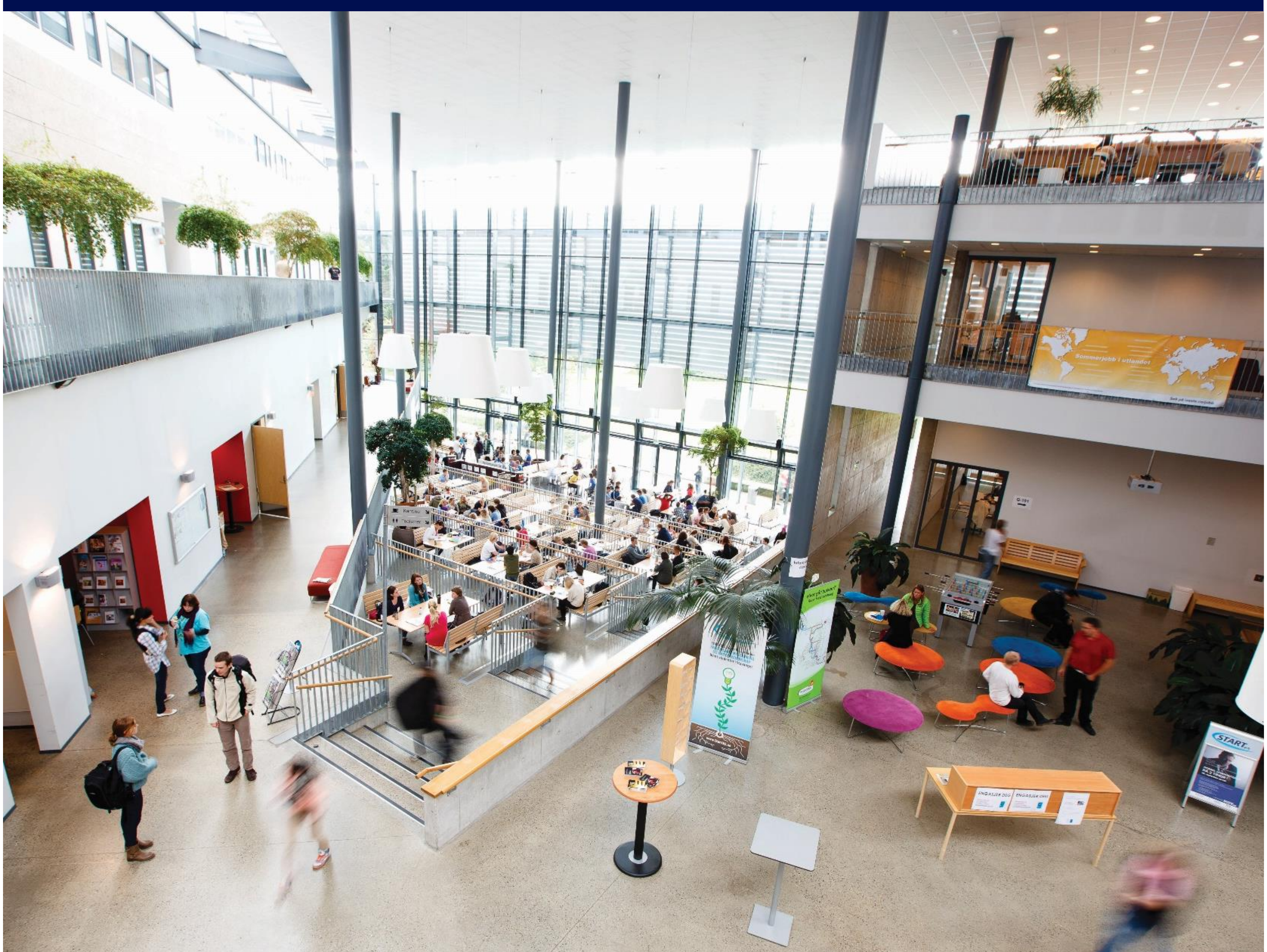

Contents

Abstract

Risk matrices are widely used across industries for visualising risk. Despite their popularity, there is a strong consensus among scholars that traditional risk matrices have significant methodological limitations. This creates a gap between industry practice and scholarly critique.

This thesis addresses this gap by investigating: *"What are the different types of Probability Consequence Diagram (PCD) designs, their theoretical foundations, practical applications, and can a structured framework be developed to assist risk assessors in selecting the most appropriate PCD adaptation based on risk characteristics?"*

To answer this research question, a scoping review of 1,873 publications was conducted, resulting in twelve distinct, generally applicable PCD adaptations. The review revealed that whilst these adaptations exhibit diverse designs and applications across industries, systematic guidance for their selection remains absent in the literature.

Building upon this scoping review, two frameworks were developed to address this gap. Framework 1 guides the selection from existing PCD adaptations, whilst Framework 2 enables the construction of PCDs through the selection of visual elements. Both frameworks operate based on risk characteristics and the visualisation's intended purpose.

This research provides the first systematic approach to matching PCD capabilities with risk management requirements, thereby bridging the gap between the theoretical understanding of limitations and the practical application needs. These frameworks form a foundation for more informed PCD selection in practice, whilst acknowledging limitations including reliance on analyst judgement and the need for empirical validation, which represents a critical area for future research.

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1 Introduction

1.1 Background

Risk matrices are widely used across industries for visualising and assessing risk. Their intuitive, colour-coded grids make them accessible and easy to use, contributing to their widespread adoption in various sectors, from engineering and healthcare to finance and public safety (Jordan et al., 2018). However, despite their popularity, there is a strong consensus among scholars that traditional risk matrices have significant methodological limitations (Aven, 2008; Cox, 2008; Duijm, 2015; Flage & Røed, 2012; Goerlandt & Reniers, 2016). This disconnect between industry reliance on risk matrices and academic critique highlights a significant gap in the literature.

To address these shortcomings, researchers have proposed various adaptations of risk matrices, incorporating additional dimensions, refined scaling methods, and alternative visualisations. Examples include bubble diagrams, heat maps, and risk plots, which aim to enhance risk communication and decision-making accuracy (Abrahamsen et al., 2014; Aven, 2013). While scholars proposing these adaptations often discuss previous models, no systematic review has mapped and evaluated these diverse adaptations. Furthermore, while axioms and requirements for risk matrices have been established, there is no existing framework guiding risk analysts in selecting an appropriate risk matrix adaptation based on the characteristics of a given risk scenario (Cox, 2008; Peace, 2017).

1.2 Objectives and research questions

This thesis seeks to bridge this gap through a two-part research approach. The first part consists of a scoping review that systematically maps the different risk matrix designs found in the literature, assesses their theoretical foundations and practical applications, and identifies their strengths and shortcomings. The second part builds on these findings to develop a structured framework that assists risk assessors in selecting the most appropriate risk matrix adaptation based on the characteristics of a given risk scenario. This leads to the following overarching research question:

"What are the different types of Probability Consequence Diagram (PCD) designs, their theoretical foundations, practical applications, and can a structured framework be developed to assist risk assessors in selecting the most appropriate PCD adaptation based on risk characteristics?"

To address this overarching question, the research is divided into two primary investigations, each formulated as a distinct research question:

1. *What are the different types of risk matrix designs, their theoretical foundations, practical applications, strong points and shortcomings?*

2. *Can a framework be developed to assist risk assessors in selecting the most suitable risk matrix adaptation based on risk characteristics, and if so, how would such a framework be structured?*

1.3 Scope and delimitations

This thesis initially focused on "risk matrices" as its primary scope of investigation. Risk matrices are commonly understood as grids that systematically map risks based on probability and consequence dimensions, helping decision-making in risk management. However, as the research progressed, it became clear that this terminology was too restrictive for the breadth of risk visualisation tools encountered in the literature.

This meant that, after completing the majority of the scoping review, the scope was expanded to adopt the broader term "Probability-Consequence Diagram" (PCD) (Ale et al., 2015). This terminology acknowledges that visualising risk through probability and consequence dimensions extends beyond matrix formats to include a variety of visual representations. The term PCD encompasses traditional risk matrices as well as more sophisticated forms that incorporate additional dimensions or abandon the grid format entirely.

The expansion of scope may have resulted in the oversight of some relevant studies. However, PCDs are typically discussed in relation to risk matrices, as risk matrices remain the predominant terminology in practice. This methodological consideration is addressed further in the limitations section found in Chapter 5.6.

To ensure consistency in this thesis, two criteria are used to determine whether a visualisation tool qualifies as a PCD:

1. **Purpose**: The tool must be designed to visualise, assess, rank, or prioritise risks, to aid in decision making.

2. **Dimensionality**: The tool must map risks along at least two dimensions—commonly likelihood (or probability) and consequence (or impact). Additional dimensions, such as uncertainty or Strength of Knowledge (SoK), may be included.

1.4 Thesis structure

This thesis is organised as follows: Chapter 2 describes the methodology, including the scoping review approach and framework development process. Chapter 3 presents the scoping review findings, identifying twelve distinct PCD adaptations and analysing their theoretical foundations, applications, strengths, and limitations. Chapter 4 introduces two complementary frameworks: Framework 1 for selecting existing PCD types and Framework 2 for constructing customised visualisations through a modular approach. Chapter 5 discusses the broader implications of the findings, methodological reflections, and future research directions. Chapter 6 concludes the thesis by answering the main research question.

2 Methods

2.1 Scoping Review

A scoping review is a research method that systematically maps literature across a broad topic area to identify concepts, theories, and research gaps (Pollock et al., 2024). This methodology was the best fit for this research for three reasons. 1) It can span multiple disciplines, including both applied risk science from various sectors and broader, more conceptual studies. 2) The methodology accepts various study types, including theoretical papers, case studies, empirical research, and grey literature such as industry standards. This inclusivity matters since developments in PCDs not only occur in scientific journals, but also in practice. 3) The methodology's iterative approach allows for refining search strategies as themes emerge, which is needed when exploring a field where terminology varies across domains.

The scoping review follows the JBI methodology for scoping reviews (Pollock et al., 2024). This scoping review used the nine steps of the JBI methodology. Table 1 shows where each step is documented in this thesis.

Table 1 JBI Methodology Steps and Documentation in This Thesis

JBI Scoping Review Steps (Pollock et al., 2024)	Thesis Section
1. Defining the objectives and questions	1. Introduction
2. Developing inclusion criteria aligned with the objectives and questions	2.1.1 Inclusion and Exclusion Criteria
3. Describing the planned approach to evidence searching, selection, extraction, and analysis	2.1 Scoping Review
4. Searching for the evidence	2.1.2 Search Strategy and 3.1 Initial Results
5. Selecting the evidence	2.1.3 Study Selection and 3.2 Title and Abstract Screening
6. Extracting the evidence	3.3 Full-text Review
7. Analysis of the results	3.4 Analysis and Discussion
8. Presentation of the results	3.4 Analysis and Discussion
9. Summarising the evidence in relation to the purpose of the review, making conclusions, and noting implications of the findings	3.5 Conclusion

2.1.1 Inclusion and Exclusion Criteria

The following inclusion and exclusion criteria were established for the scoping review.

Inclusion Criteria

1. Type of publications: Empirical studies, theoretical papers, and literature reviews that describe risk matrix designs, their development, applications, or evaluations. As well as industry-specific publications with explanations of specific risk matrix adaptations.

2. Timeframe: The publication date will not be limited, as risk matrices are a relatively new concept.

Exclusion Criteria

1. Publications that do not describe risk matrix designs or applications in depth.

2. Publications focused on applying risk matrices to one application instead of focusing on the risk matrix methodology.

3. Publications without a scientific research component.

4. Publications that cannot be accessed online through the University of Stavanger.

5. Publications written in a language other than English, Dutch or Norwegian.

2.1.2 Search Strategy

The initial search query consisted of the following search terms and Boolean operators:

("Risk matrix" OR "Risk matrice" OR "Risk matrices" OR "Risk visualization" OR "Risk visualisation" OR ''Risk Heatmap'' OR '' PI Graph'') AND ("Evaluation" OR "Efficacy" OR "Application" OR "Design" OR "Framework").

Databases and Search Engines:

Oria was used as the initial database for the scoping review. Oria is a search engine used by Norwegian academic libraries for unified searches across books, journals and articles. After this, the same search query was run in Scopus to ensure that any relevant sources unavailable through Oria were also covered.

2.1.3 Study Selection

The study selection process consisted of two stages.

Stage 1: Title and Abstract Screening

Initial screening evaluated titles and abstracts against the inclusion and exclusion criteria. Studies were included if they explicitly mentioned risk matrices, their design, theoretical foundations, or applications. Studies that met any exclusion criteria were removed.

Stage 2: Full-Text Review

Publications that passed the initial screening underwent a full-text review. Each article was assessed against the inclusion and exclusion criteria to determine final eligibility. Articles that failed to provide substantial information about risk matrix design or adaptation, or focused solely on application-specific implementations without methodological discussion, were excluded. Access limitations were addressed with the assistance of librarians at UIS, but publications that remained inaccessible despite these efforts were excluded from the review.

2.1.4 Reporting and discussion

Results are organised in tables categorising studies by their primary focus (Scientific Foundation, Industry Application, or Risk Management and Decision-Making). Studies were also categorised with relevance ranging from – meaning irrelevant to the research question to ++ highly relevant for answering the research question. This long list of categorised publications formed the starting point for discussing the relevant PCD adaptations.

2.2 Framework Development

The development of the Risk Matrix Selection Framework followed the methodological approach outlined by (McMeekin et al., 2020) which provides a three-phase process for developing methodological frameworks.

2.2.1 Phase 1: Identifying Evidence to Inform the Framework

The scoping review provided the evidence base for developing the framework. The review began with a broad scope to map existing literature whilst refining the research question. The scoping review identified twelve distinct PCD adaptations and analysed their theoretical foundations, practical applications, strengths, and limitations. The process revealed gaps in existing guidance for PCD selection, with only one framework-like structure identified in the literature (Peace, 2017).

2.2.2 Phase 2: Developing the Framework

Framework development employed an iterative approach combining individual analysis with expert consultation. The process involved:

Data synthesis and categorisation: The twelve PCD adaptations were analysed to extract common risk characteristics that influenced their effectiveness.

Conceptual development and visualisation: Multiple framework iterations were made through brainstorming sessions using digital tools such as ChatGPT and Claude AI for text-based development and diagram creation, as well as traditional methods including drawing and writing. These steps facilitated the identification of relevant relationships between elements.

Regular discussions with the thesis supervisor provided feedback on framework concepts. These consultations involved presenting concepts, discussing challenges, and exploring improvements.

2.2.3 Phase 3: Evaluate and Refine

The evaluation phase was implemented through fictitious case studies. Comprehensive empirical validation fell beyond the scope of this thesis. The case studies establish a foundation for future empirical research by providing an example for testing the framework using real-world applications.

3 Scoping Review

3.1 Initial results

The previously mentioned search query was used as the basis for the scoping review. This search yielded 2,668 results. However, the maximum number of papers that could be displayed was 2,000. This limitation excluded 668 publications from the review. Nevertheless, the papers were sorted by relevance, ensuring that the most relevant publications for this study were prioritised and likely included in the analysis. Table 1 shows the Search results categorised by resource type. Tabel 2 shows the number of sources per Journal.

Table 2 Search Results by Resource Type

Resource Type	Count
Articles	2,255
Peer-Reviewed Journals	2,130
Conference Proceedings	281
Book Chapters	193
Books	83
E-Books	48
Master Theses	32
Dissertations	24
Reports	18
Magazine Articles	13
Text Resources	4
Doctoral Thesis	3
Other*	7

*"Other" includes Reference Entries (2), Archival Material/Manuscripts (2), Print Books (1), Web Resources (1), and Book Reviews (1).

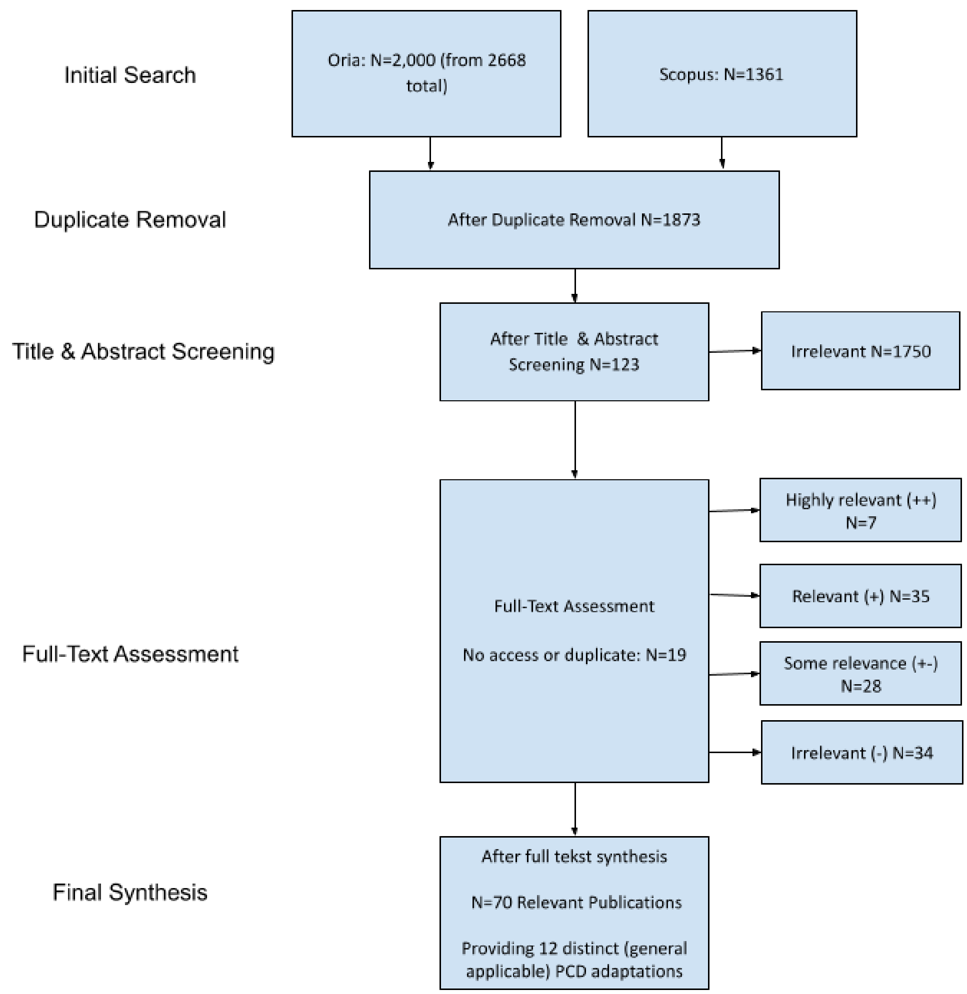
Table 3 Search Results by Journal

Journal name	Count
Journal of Loss Prevention in the Process Industries	40
IOP Conference Series: Earth and Environmental Science	31
PLOS One	30
Safety Science	26
Risk Analysis	25
Scientific Reports	23
International Journal of Environmental Research and Public Health	21
Environmental Science and Pollution Research International	19
IOP Conference Series: Materials Science and Engineering	18
Blood	27

The 2000 sources were exported to EndNote, and the EndNote library was exported to Rayyan (Rayyan, 2025). Duplicates were resolved using Rayyan's 95% similarity feature. Other possible duplicates (duplication scores between 10% and 95%) were reviewed manually.

After removing the duplicates, the same search query was run in Scopus. The Scopus query resulted in 1361 results. When the citations were added to Rayyan and compared with the Oria results, 1097 additional duplicates were found. Duplicate articles with a 95% similarity or more were auto-resolved using Rayyan. This left 247 unresolved (potential) duplicates, which were manually resolved. This left 1873 for the title and abstract screening.

Figure 1 PRISMA Flow Diagram: Visualisation of the Study Selection Process



3.2 Title and abstract screening

The 1873 sources were reviewed based on the previously mentioned inclusion and exclusion criteria, focusing on their titles and abstracts. In total, 103 publications complied with the inclusion and exclusion criteria. These publications were categorised into four different categories, and an indication of their relevance to the current study was given. Some papers were attributed to multiple categories.

Categorising:
Industry application (IA): Focus on the application of a specific form of risk matrix in an applied setting.
Scientific foundation (SF): Focus on discussing the scientific foundations of the risk matrix.
Risk management and decision-making (R&DM): Focus on the influence the type of risk matrix has on the decision-making process.

Relevance to the main research question:
++: Highly relevant
+: Relevant
+-: Some relevance
-: Not relevant at all and to be excluded

The complete list of the 103 papers, with their original categorisation and relevance, is included in Appendix 1.

3.3 Full-text review

The relevant (+) highly relevant papers and book chapters (++) have been fully analysed. For each of these papers and chapters, the adaptation of the Risk matrix is described, along with the main findings, conclusions, and/or arguments. These findings are summarised in Tables 3 to 5. Table 3 summarises the papers focused on IA, Table 4 on SF, and Table 5 on R&DM. Some publications could be attributed to multiple categories. For readability, these publications are listed once only under their most predominant category. The complete categorising can be found in Appendix 1. Some of the publications led to other relevant studies. These papers are not included in the table below but are referenced using in-text citations.

Table 4 Industry application

Source	PCD discussed	Main points
American Institute of Chemical Engineers, Center for Chemical Process Safety. (2019). Using LOPA and risk matrices in risk decisions. In *Guide for making acute risk decisions* (pp. 151-172). Wiley. https://doi.org/10.1002/9781119669043.ch9	-Quantitative, qualitative and semi-qualitative risk matrices -Risk matrix with FN- curves -Risk criteria matrix -BASF risk matrix -BP's group societal risk profile	Multiple examples of practical applications of risk matrices in safety management
Bao, C., Wu, D., Wan, J., Li, J., & Chen, J. (2017). Comparison of Different Methods to Design Risk Matrices from The Perspective of Applicability. Procedia computer science, 122, 455-462. https://doi.org/10.1016/j.procs.2017.11.393	Risk Matrix with ISO contours	Comparison of Risk Matrix methods in relation to the axioms by Cox (2008)
Elmontsri, M. (2014). Review of the Strengths and Weaknesses of Risk Matrices. Journal of risk analysis and crisis response, 4(1), 49. https://doi.org/10.2991/jrarc.2014.4.1.6	-Quantitative risk matrix -Semi-quantitative risk matrix -Qualitative risk matrix -NHS risk matrix	Risk matrices can serve effectively as presentation tools for simplified risk analysis. Organisations should customise matrix design and dimensions to align with specific operational requirements and contexts.
Hubbard, D. W. (2020). A Summary of the Current State of Risk Management. In (pp. 21-34). Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/9781119521914.ch2	Simple Quantitative Representation with confidence intervals	Includes a study on the percentage of companies that use risk matrices. Also presents a simple quantitative risk matrix with confidence intervals
Mitterhofer, H., Jordan, S., Zinn, J. O., Burgess, A., & Alemanno, A. (2016). Imagining risk: The visual dimension in risk analysis. In (pp. 318-334). Routledge. https://doi.org/10.4324/9781315776835-37	Traditional (semi-) quantitative risk matrices	The background of different types of risk visualisations is explained
Plotnikov, N. I., Mendes de Seixas, A. C., Gomes de Oliveira, G., Saotome, O., Iano, Y., Kemper, G., Saotome, O., Gomes de Oliveira, G., Mendes de Seixas, A. C., Iano, Y., & Kemper, G. (2021). Soft Computing Method in Events Risks Matrices. In (Vol. 233, pp. 578-588). Switzerland: Springer International Publishing AG. https://doi.org/10.1007/978-3-030-75680-2_64	Several risk (semi) quantitative risk matrix adaptations specific to the space sector.	Proposes the use of "soft computing" techniques, incorporating various measures

Table 5 Scientific Foundation (SF)

Source	PCD discussed	Main points
Aven, T. (2008). Discussion. In *Risk analysis: Assessing uncertainties beyond expected values and probabilities* (pp. 143-166). John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470694435.ch13	-Traditional quantitative and qualitative risk matrices -Risk matrix with multiple consequences for one risk event	A risk matrix is a tool for describing risk
Aven, T. (2017). Improving risk characterisations in practical situations by highlighting knowledge aspects, with applications to risk matrices. Reliability engineering & system safety, 167, 42-48. https://doi.org/10.1016/j.ress.2017.05.006	Conceptual extended risk matrix with knowledge dimensions	Practical methods are reviewed and discussed, in particular, extended risk matrices
Aven, T., & Thekdi, S. (2022). Measuring and describing risk. In (pp. 24-58). Routledge. https://doi.org/10.4324/9781003156864-4	-Traditional (semi) quantitative risk matrix -Semi-quantitative risk matrix with knowledge judgements -Risk matrix with fixed consequences , probabilities, and knowledge judgements	Extensive scientific background on measuring risk
Ball, D. J., & Watt, J. (2013). Further Thoughts on the Utility of Risk Matrices. Risk Analysis, 33(11), 2068-2078. https://doi.org/10.1111/risa.12057	Qualitative 5x5 matrix	The authors agree with the findings from Cox 2008, except for that risk matrices are too embedded into society to be removed
Baz, J., Martinez, M., Diaz-Vazquez, S., & Montes, S. (2024). On the Construction of Admissible Orders for Tuples and Its Application to Imprecise Risk Matrices. International journal of computational intelligence systems, 17(1), 1-14. https://doi.org/10.1007/s44196-024-00575-9	Imprecise risk matrix with boxes	There is a need for imprecise risk matrices in order to have risk analysts express more uncertainty
Cox, A. L., Jr. (2008). What's Wrong with Risk Matrices. Risk Anal, 28(2), 497-512. https://doi.org/10.1111/j.1539-6924.2008.01030.x	Quantitative and semi-quantitative risk matrices	Risk matrices can produce bad results when probability and consequence are negatively correlated, but may be beneficial when sufficient data is available. The conditions determining their effectiveness remain poorly understood.
Cox, L. A., Jr. (2009). What's Wrong with Hazard-Ranking Systems? An Expository Note. Risk Anal, 29(7), 940-948. https://doi.org/10.1111/j.1539-6924.2009.01209.x	No specific PCD adaptation mentioned	Risk priority scoring should not be used to determine optimal risk reduction. Instead, other methods, such as portfolio optimisation, should be preferred.
Duijm, N. J. (2015). Recommendations on the use and design of risk matrices. Safety science, 76, 21-31. https://doi.org/10.1016/j.ssci.2015.02.014	PCD with uncertainty boxes	Logarithmic scaling is recommended. Colouring should be fading.
Goerlandt, F., & Reniers, G. (2016). On the assessment of uncertainty in risk diagrams. Safety science, 84, 67-77. https://doi.org/10.1016/j.ssci.2015.12.001	-PCD with uncertainty boxes -Bubble diagram -Risk plot -PCD with Tukey Box Plots -PCD with the strength of evidence and assumption deviation	Measurements of uncertainty besides probability need to be included in visualisations of risk. Strength of Evidence assessments need to be divided into Data, judgment and Model.
Høj, N. P., Kroon, I. B., Nielsen, J. S., & Schubert, M. (2025). System risk modelling and decision-making – Reflections and common pitfalls. Structural safety, 113, 102469. https://doi.org/10.1016/j.strusafe.2024.102469	-Traditional semi-quantitative risk matrix -FN-Curves	Risk categorisation and aggregation must align with fundamental risk definitions. Decision-making should employ formal decision analysis rather than relying on risk matrices or FN-curves, incorporating implementation costs of preventive measures.
Hong, Y., Pasman, H. J., Quddus, N., & Mannan, M. S. (2020). Supporting risk management decision making by converting linguistic graded qualitative risk matrices through interval type-2 fuzzy sets. Process safety and environmental protection, 134, 308-322. https://doi.org/10.1016/j.psep.2019.12.001	Three-dimensional fuzzy risk matrix	A new methodology for creating fuzzy risk matrices
Jensen, R. C., & Hansen, H. (2020). Selecting Appropriate Words for Naming the Rows and Columns of Risk Assessment Matrices. International journal of environmental research and public health, 17(15), 5521. https://doi.org/10.3390/ijerph17155521	Qualitative risk matrix variations	The complexity of a risk matrix should align with the expertise of its users. Future research should compare results from experienced OSH professionals with those from the student population used in this study. Table continues on the next page->

Jørgensen, L., Lindøe, P. H., Lindøe, P. H., Juhl, K., Olsen, O. E., & Engen, O. A. (2020). Standardizations and risk mapping: Strengths and weaknesses. In (pp. 181-198). Routledge. https://doi.org/10.4324/9780429290817-14	Traditional semi-quantitative 5x5 risk matrix	Using standardised formats can increase risk
Levine, E. S. (2012). Improving risk matrices: the advantages of logarithmically scaled axes. Journal of risk research, 15(2), 209-222. https://doi.org/10.1080/13669877.2011.634514	Risk matrix with logarithmic scales	A logarithmic risk matrix aligns better with the axioms defined by Cox (2008)
Li, J., Bao, C., & Wu, D. (2018). How to Design Rating Schemes of Risk Matrices: A Sequential Updating Approach. Risk Anal, 38(1), 99-117. https://doi.org/10.1111/risa.12810	Traditional (semi) quantitative 3x3 and 5x5 risk matrices	New method for determining cell level in adherence to Cox (2008)
Oboni, F., & Oboni, C. H. (2021). Risk assessments don'ts. In *Convergent leadership-divergent exposures* (pp. 337-349). Springer International Publishing. https://doi.org/10.1007/978-3-030-74930-9	Risk matrices (general)	Risk matrices should not be used
Peeters, W., & Peng, Z. (2015). An Approach Towards Global Standardization of the Risk Matrix. Journal of space safety engineering, 2(1), 31-38. https://doi.org/10.1016/S2468-8967(16)30037-4	Qualitative risk matrix	Proposes a standardised framework to improve consistency in risk matrix use in the space sector
Rausand, M., & Rausand, M. (2011). How to Measure and Evaluate Risk. In (pp. 77-116). Hoboken, New Jersey: John Wiley & Sons, Inc. https://doi.org/10.1002/9781118281116.ch4	Traditional risk matrix	Traditional risk matrix explained and the use of linear and logarithmic scales.
Schmidt, M. S. (2016). Making sense of risk tolerance criteria. Journal of loss prevention in the process industries, 41, 344-354. https://doi.org/10.1016/j.jlp.2015.12.005	Multi-consequence scale risk matrix with risk tolerance criteria	Risk tolerance criteria can aid decision making, but are difficult to establish and implement correctly
Slavin, D., Troy Tucker, W., Ferson, S., Tucker, W. T., Ferson, S., & Finkel, A. M. (2008). A Frequency/Consequence-based Technique for Visualizing and Communicating Uncertainty and Perception of Risk. Ann N Y Acad Sci, 1128(1), 63-77. https://doi.org/10.1196/annals.1399.008	Manipulative Probability – Adversity Graph with Burden of Proof, Dispute tolerance and Uncertainty display sliders	Visualising uncertainties in a software application
Tiusanen, R., Rollenhagen, C., Ove Hansson, S., Moller, N., & Holmberg, J. E. (2017). Qualitative Risk Analysis. In (pp. 463-492). Hoboken, NJ, USA: John Wiley & Sons, Inc. In the Handbook of Safety Principles https://doi.org/10.1002/9781119443070.ch21	A traditional risk matrix and a risk scatter plot	Use cases and limitations of risk matrices are discussed from various angles
Vaezi, A., Jones, S., & Asgary, A. (2024). Integrating Resilience into Risk Matrices: A Practical Approach to Risk Assessment with Empirical Analysis. Journal of risk analysis and crisis response, 13(4), 252-272. https://doi.org/10.54560/jracr.v13i4.411	Risk Heat Map	Weighing risks with resilience as an added component
Ward, S., & Chapman, C. (2012). Uncertainty, risk and opportunity. In (pp. 43-71). Hoboken, NJ, USA: John Wiley & Sons, Inc. In the Handbook of Safety Principles https://doi.org/10.1002/9781119208587.ch2	Traditional risk matrix and a risk scatter plot	Also part of the handbook of safety principles
Cox, L. A., Jr. (2009). Limitations of risk assessment using risk matrices. In *Risk analysis of complex and uncertain systems* (pp. 101-124). Springer. https://doi.org/10.1007/978-0-387-89014-2_4	Quantitative 2x2, 3x3, 4x4, and 5x5 risk matrices	Limitations of risk matrices explained using axioms. *'More research is urgently needed to better understand under which conditions risk matrices are helpful or harmful in risk management decision making''(Cox, 2009, p. 123)*
Peace, C. (2017). The risk matrix: Uncertain results? Policy and Practice in Health and Safety, 15(2), 131-144. https://doi.org/doi:10.1080/14773996.2017.1348571	Basic example of a risk matrix	Risk matrices are not congruent with the ISO 3100 risk definition
Hefaidh, H., & Mébarek, D. (2020). A conceptual framework for risk matrix capitalization. International journal of system assurance engineering and management, 11(3), 755-764. https://doi.org/doi:10.1007/s13198-020-00949-0	Qualitative 5x5 Risk Matrix	Using Experience Feedback as a way of analysing risk for proper placement in the risk matrix
Flage R, Røed W. A reflection on some practices in the use of risk matrices. Pp. 881–891 in 11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012. Vol 2. 2012.	-Opportunity matrix -Bubble diagram with manageability dimension	Risk matrices are useful when risk assessors and decision makers understand their limitations. Further research is needed on when risk matrices are helpful and when they are not.
Fan, C., Montewka, J., Zhang, D., & Han, Z. (2024). A framework for risk matrix design: A case of MASS navigation risk. Accident Analysis and Prevention, 199. https://doi.org/doi:10.1016/j.aap.2024.107515	A variety of (classic) (semi-) qualitative risk matrix adaptations	A framework for developing a risk matrix based on fuzzy Analytic Hierarchy Process (AHP) is proposed. The framework is designed in relation to Autonomous shipping
Entacher, M., & Sander, P. (2018). Improving: Risk matrix design using heatmaps and accessible colors. Journal of Modern Project Management, 6(1), 30-37. https://doi.org/doi:10.19255/JMPM01603	Various heatmaps and semi-quantitative risk matrices	Considerations on colour designs and the use of heat maps instead of grids

Table 6 Risk Management and Decision making (R&DM)

Source	PCD discussed	Main points
Bier, V. (2020). The Role of Decision Analysis in Risk Analysis: A Retrospective. Risk Anal, 40, 2207-2217. https://doi.org/10.1111/risa.13583	Method for reflecting decision-maker risk attitudes in risk matrices, something Ruan, Yin, and Frangopol (2015) Sequential revisions of risk matrices Li, Bao, and Wu (2018) .	Review on the combination of risk analysis and decision making from the risk analysis journal
Jordan, S., Mitterhofer, H., & Jørgensen, L. (2018). The interdiscursive appeal of risk matrices: Collective symbols, flexibility normalism and the interplay of 'risk' and 'uncertainty'. Accounting, organizations and society, 67, 34-55. https://doi.org/10.1016/j.aos.2016.04.003	Wide range of risk visualisations from basic risk matrices to infographics	*''..risk matrices are appealing to different users in divers application contexts, as they link – through their use of collective symbols – specialized and everyday discourse'' p.52* Recommendations on further research on accounting perceptions in relation to visualisations, but not specific to risk matrices.
Lane, K., & Hrudey, S. E. (2023). A critical review of risk matrices used in water safety planning: improving risk matrix construction. J Water Health, 21(12), 1795-1811. https://doi.org/10.2166/wh.2023.129	12 risk matrices adapted for water management	Comparison of different types of risk matrices in water management using the axioms proposed by Cox 2008
Proto, R., Recchia, G., Dryhurst, S., & Freeman, A. L. J. (2023). Do colored cells in risk matrices affect decision-making and risk perception? Insights from randomized controlled studies. Risk Anal, 43(10), 2114-2128. https://doi.org/10.1111/risa.14091	4 colour 5x5 risk matrix	Some evidence that colour assignment in risk matrices influences people's perception of risk gravity Future research is needed to tell how strong the 'boundry crossing effect' is.
Reniers, G. L. L., & Sörensen, K. (2013). An Approach for Optimal Allocation of Safety Resources: Using the Knapsack Problem to Take Aggregated Cost-Efficient Preventive Measures. Risk Analysis, 33(11), 2056-2067. https://doi.org/10.1111/risa.12036	Traditional risk matrix	Analysis of the costs and risk-reducing measures in matrices.
Sutherland, H., Recchia, G., Dryhurst, S., & Freeman, A. L. J. (2022). How People Understand Risk Matrices, and How Matrix Design Can Improve their Use: Findings from Randomized Controlled Studies. Risk Anal, 42(5), 1023-1041. https://doi.org/10.1111/risa.13822	Semi-quantitative risk matrix with logarithmic axes	Suggestion of the use of different-shaped fields to increase logarithmic awareness in matrices
Nicholls, C., & Carroll, J. (2017). Is there value in a 'one size fits all' approach to risk matrices? (Vol. 2017). https://www.icheme.org/media/15553/poster-14.pdf	3x3, 5x5 and 7x7 risk matrix examples	A standardised risk matrix will most certainly not provide good results, as the use of the risk matrix determines how it should be made.

3.4 Analysis and Discussion

The discussion chapter is structured as follows. First of all, a general description of the literature review findings is provided. After this, twelve PCD adaptations are described. For each of the adaptations, the sub-questions from the scoping review are addressed by describing the following aspects of each PCD: 1) description of the PCD, 2) theoretical foundation of the PCD, 3) scientific gaps or shortcomings identified with the adaptation and 4) practical application of the PCD.

3.4.1 General findings

The literature on PCDs primarily focuses on their application within specific industries and distinct risk management problems. Few studies address the general framework of PCDs or examine their applicability across various domains. Cox's (2008) work remains the most influential in this area, with other scholars using his axioms to determine the effectiveness of new PCD adaptations (Lane & Hrudey, 2023). The studies that do address PCD in general terms are, by and large, conceptual studies. Sutherland (2018) and Proto (2023) were the only quantitative empirical studies on the effectiveness of a general PCD adaptation found in this review.

3.4.2 Risk matrix adaptations

Twelve different, generally applicable PCDs have been identified. These variations build upon the traditional framework by incorporating additional dimensions and elements, redefining scales, and using different colours. The PCD adaptations are discussed from simple (a traditional risk matrix) to complex (multiple variables). In this way, we can build upon the characteristics, strengths, and weaknesses of previous adaptations to explain and compare more complex visuals.

3.4.2.1 Traditional Risk Matrix

Figure 2 Example of a Traditional Qualitative Risk Matrix

Severity / Likelihood	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	[Green]	[Yellow]	[Red]	[Red]	[Red]
Probable B	[Green]	[Yellow]	[Red]	[Red]	[Red]
Remote C	[Green]	[Yellow]	[Yellow]	[Red]	[Red]
Extremely Remote D	[Green]	[Green]	[Yellow]	[Yellow]	[Red]
Extremely Improbable E	[Green]	[Green]	[Green]	[Yellow]	[Red] * / [Yellow]

High Risk [Red]
Medium Risk [Yellow]
Low Risk [Green]

* High Risk with Single Point and/or Common Cause Failures

Figure C-1: Risk Matrix – Commercial Operations/Large Transport Category

Note. From Safety Risk Management Policy (Order 8040.4B) (p. C3), by FAA, 2017 (https://www.faa.gov/documentLibrary/media/Order/FAA_Order_8040.4B.pdf). In the public domain.

Description

For this thesis, I define the traditional risk matrix as a matrix consisting of probabilities on one axis and consequences on the other, utilising a grid. Different terminology for the axes can also be used, such as likelihood and severity. Consequences are usually plotted on the x-axis and probabilities on the y-axis, though this orientation can be reversed. Either numbers (quantitative), words (qualitative), or a combination of both (semi-quantitative) can be used to express probabilities and consequences, leading to different types of risk matrices with varying degrees of precision.

Most risk matrices visualise only negative consequences, although positive outcomes can also be represented. Either separate, in an 'opportunity matrix' or combined. The dimensions of the matrix are not fixed, but 3×3 and 5×5 designs are common. Each cell in the matrix is assigned a colour, with green, yellow and red often used as the standard scheme. Different colourings are also used, such as gradients from light to intense red, or other colour schemes entirely. When three colours are used, they typically represent three risk categories with definitions along the lines of the following (Renn, 2008):

- Green: Acceptable risks where no further risk-reducing measures are necessary
- Yellow: Risks that should be addressed according to the As Low As Reasonably Practicable (ALARP) principle
- Red: Unacceptable risks where operations cannot continue until risk-reducing measures are implemented

Theoretical Foundation

The traditional risk matrix is grounded in mathematical and economic principles. To fully comprehend the theory of the risk matrix, it is helpful to outline the steps required in its construction and the theoretical considerations at each stage.

Step 1: Choosing a Risk Factor Formula

Risk matrices visualise risk levels, which means that typically the first step is selecting a formula to determine these levels, referred to as the risk factor formula. This formula is closely related to the risk definition used by the risk assessor and serves as the foundation for the risk matrix design. In the traditional risk matrix, this formula is typically probability multiplied by consequence (P×C). The P×C formulation implies a specific philosophical stance toward risk that focuses on expected outcomes rather than uncertainty, which has been subject to substantial theoretical critiques in risk science (Aven, 2013).

It should be noted that a risk matrix can be constructed without a mathematical formula. In such cases, risk levels (represented by colours or categories) are assigned directly to matrix cells. Nevertheless, a formula-based approach remains the most common starting point in risk matrix design.

This mathematical approach to risk emerged from early probability theory, which forms the foundation of quantitative risk assessment. As Ale et al. (2015) note in their historical review of probability-consequence diagrams, the concept of expressing risk as a function of probability and consequence has deep historical roots, dating back to decision-making principles in the early 1700s that weighed the gravity of potential harm against the probability of its occurrence.

For the plotting of the risks in the matrix, this means that all risks with equal P and C values are assigned the same risk level regardless of their specific characteristics. It treats all combinations with the same product as equivalent (e.g., high probability/low consequence and low probability/high consequence events). Mathematically, this creates a family of hyperbolic isocontours on the risk matrix, where all points along each hyperbola have the same risk value (if plotted on a linear scale). See figure 3 for an example.

Step 2: Establishing Consequence Scales

Creating a consequence scale involves quantifying the severity of outcomes. Linear consequence scales assume that each incremental increase in consequence severity is equally significant. However, this assumption contradicts empirical evidence about how humans value consequences. Psychometric studies have demonstrated that perceived consequence severity often follows a logarithmic rather than linear progression, especially for large-magnitude events (Fischhoff et al., 1978).

Logarithmic consequence scales, where each step represents an order of magnitude increase, therefore, better align with human perception (Levine, 2012). Logarithmic scaling also addresses some of the mathematical concerns raised by Cox regarding risk matrix consistency (Cox 2008).

The theoretical underpinning of consequence scales also involves the problem of commensurability. This means that different types of consequences (financial, health, environmental) are compared on a single scale. This creates a dilemma between theoretical rigour (maintaining separate scales for different consequence types) and practical utility (enabling comparison across consequence types).

Step 3: Establishing Likelihood Scales

Likelihood scales in risk matrices represent the probability or frequency dimension of risk. Traditional risk matrices employ various approaches to likelihood scaling, each with different implications.

In practice, both frequentist probabilities (based on historical frequencies of events) and knowledge-based probabilities (representing degrees of belief) are used. The choice often depends on the availability of data. Frequentist approaches are more common for risks with substantial historical data, while knowledge-based probabilities are employed for rare or novel events.

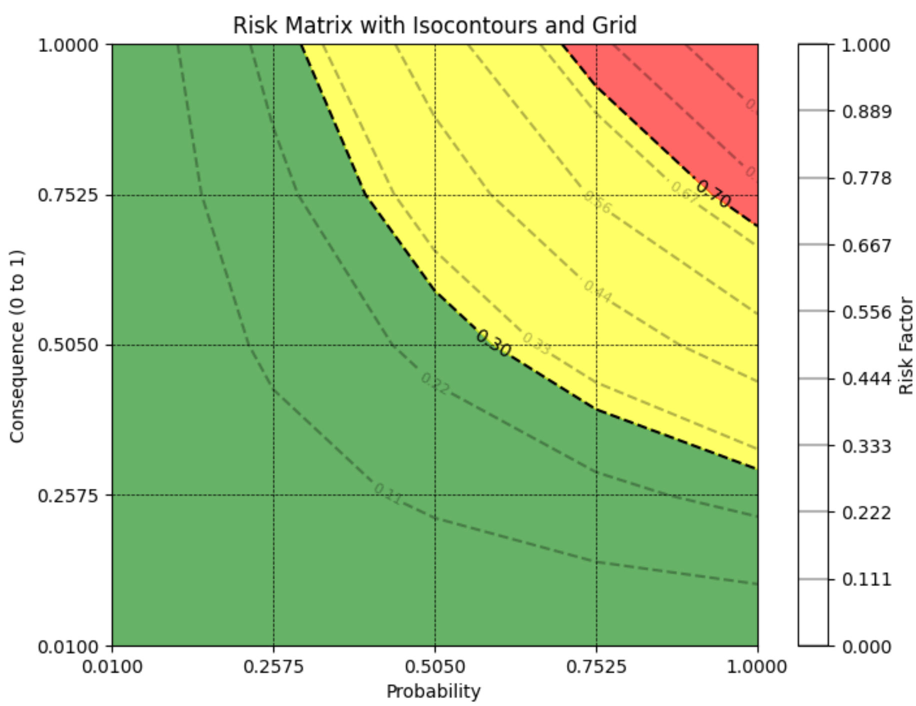
Likelihood can be expressed using qualitative descriptors (e.g., "rare," "unlikely," "possible," "likely," "almost certain") or quantitative measures (e.g., numerical probabilities or frequencies). Qualitative or 'fuzzy' scales are often preferred for communication with non-technical stakeholders, while quantitative scales provide greater precision but require more understanding of probability concepts.

Just as for the consequence scale, the spacing between likelihood categories is a consideration. Both linear scales (where intervals between categories are equal) and logarithmic scales (where each category represents an order of magnitude increase) are common in practice. Cox (2008), Duijm (2015), and Levine (2012) advocate for logarithmic scaling as it better accommodates the wide range of probabilities encountered in risk assessment and aligns with the mathematical properties required for consistent risk evaluation.

Step 4: Drawing the ISO contours

Isocontours in risk matrices are lines connecting points of equal risk value. In traditional risk matrices with linear scaling, these contours form hyperbolas, as all probability-consequence combinations with the same product lie along the same curve.

Figure 3 Risk Matrix with Isocontours and Grid



Note. From "How to make a Traditional Quantitative Risk Matrix from Scratch," by (Gaastra, 2025)(https://joukegaastra.com/how-to-make-a-traditional-quantitative-risk-matrix-form-scratch/). Python code for this figure was generated using ChatGPT.

Step 5: Defining Risk Thresholds

Risk thresholds in matrices define boundaries between different risk categories, determining which combinations of likelihood and consequence fall into acceptable, intermediate, or unacceptable risk regions.

Theoretically, these thresholds should represent risk criteria established by decision-makers or regulatory bodies, providing a tangible representation of an organisation's risk tolerance. In practice, however, threshold setting often lacks a rigorous foundation (Schmidt, 2016).

Step 6: Colour Coding

Traditional risk matrices typically employ colour schemes ranging from green (acceptable risk) to red (unacceptable risk). This traffic light colour scheme leverages established cultural associations where red signals danger, yellow indicates caution, and green signals safety or permission to proceed (Jordan et al., 2018). While this coding system aids intuitive interpretation, it also imposes a discrete categorisation on what is mathematically a continuous risk space.

Step 7: Grid Construction

The final grid layout of a risk matrix divides the continuous risk space into discrete cells. This discretisation process introduces inherent mathematical limitations that affect the matrix's performance as a risk assessment tool.

The choice of grid granularity (e.g., 3×3 versus 5×5) reflects a trade-off between discriminatory power and reliability. Coarser grids (fewer cells) provide less apparent precision but may better match the reliability of the underlying judgments, while finer grids suggest greater precision that may exceed the actual certainty of the assessments.

The placement of grid lines directly affects which probability-consequence combinations fall into which risk categories. Small adjustments to grid line positions can change the classification of multiple risks, highlighting the sensitivity of risk matrices to minor design decisions.

Cox's (2008) mathematical analysis demonstrates fundamental limitations in this discretisation approach. His work proves that even with optimal grid placement, a risk matrix cannot correctly rank-order more than a small fraction of randomly selected risk pairs. This limitation stems from the inherent mathematical constraints of representing a continuous two-dimensional space with a discrete grid.

The grid structure also introduces "range compression," where quantitatively different risks receive identical classifications, and creates the potential for "rank reversals," where a risk with lower quantitative value receives a higher qualitative rating than a risk with higher quantitative value.

Scientific Gaps and Limitations

Cox’s influential 2008 paper "What's Wrong with Risk Matrices" offers the most comprehensive theoretical critique of traditional risk matrices. Cox establishes three fundamental axioms a risk matrix should satisfy to provide logical and consistent risk assessments.

1. Weak Consistency

Weak consistency requires that the qualitative categorisation of risks in a matrix (e.g., low, medium, high) must align with the underlying quantitative risk values. A risk matrix satisfies weak consistency if alternatives in its highest risk category (e.g., "red") represent genuinely higher quantitative risks than those in its lowest risk category (e.g., "green").

This axiom formalises a fundamental expectation about risk matrices, that they should, at minimum, correctly discriminate between very high and very low risks. Mathematically, Cox proves that this seemingly basic property imposes significant constraints on matrix design. Specifically, red cells cannot share edges with green cells in a matrix satisfying weak consistency.

2. Betweenness

The betweenness axiom indicates that when risk increases continuously from a low value to a high value, its qualitative categorisation should pass through intermediate risk categories. In practical terms, this means that any positively sloped line segment passing from a green cell to a red cell must traverse at least one intermediate (e.g., "yellow") cell.

3. Consistent Colouring

The third axiom, consistent colouring, requires that cells containing similar quantitative risk values receive the same qualitative risk rating. While this cannot be achieved perfectly in a discrete matrix, Cox suggests that cells containing risk contours that pass through red cells should themselves be red (unless they also contain green contours), and cells containing green contours should themselves be green (unless they also contain red contours).

Cox's mathematical analysis demonstrates that these three axioms impose significant constraints on risk matrix design. For instance, no red cells can appear in the bottom row or the leftmost column of the matrix. In a 5×5 matrix interpreted quantitatively, only three colours are logically justified, any additional colours create spurious resolution and potentially rank-reversal errors.

These theoretical constraints explain many practical limitations of traditional risk matrices, particularly their limited ability to correctly discriminate between different risks. Cox's work suggests that approximately 90% of randomly selected pairs of risks cannot be correctly and unambiguously rank-ordered by a standard risk matrix, significantly limiting their utility as decision support tools.

Lastly, Cox demonstrates that in certain circumstances, particularly when probability and consequence are negatively correlated, risk matrices can lead to "worse than useless" results, where following the matrix recommendations would produce worse outcomes than random decision-making.

Practical Application

Traditional risk matrices are widely used across various industries due to their simplicity and intuitive visual representation. They often serve multiple purposes, from the broad goal of communicating risk through a visualisation to more specific related purposes such as visualising compliance with risk criteria, risk comparison, risk prioritisation and determining which risk-reducing measures to implement.

By discussing the theoretical foundations and limitations of the traditional risk matrix, we have seen that there are significant limitations to using it for these purposes. These limitations are related to the purpose for which the risk matrix is used and the characteristics of the risks being plotted into it. By defining these, we can develop a set of purposes and risk characteristics that align well with the traditional risk matrix or, inversely, identify a set of characteristics and purposes for which it is likely to perform poorly.

Table 7 Suitability of the traditional risk matrix

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Well-understood risks with low uncertainty in probability and consequence estimates	High uncertainty situations with limited data or knowledge
Risk definition	Contexts where a P,C definition is ap propriate (large portfolios, narrow probability distributions)	Contexts where expected values misrepresent risk (e.g., high variance or highly skewed distributions)
Correlation	Positively correlated risks (probability and consequence increase together)	Negatively correlated risks (rare catastrophic events vs frequent minor incidents)
Risk criteria	Well-established risk criteria	Unclear risk criteria
Variability and correlation	Low variability in consequences and probability estimates, where expected values provide meaningful information. Positively correlated risks (probability and consequence increase together)	Highly variable and negatively correlated consequences and probability estimates
Purpose		
Communication	Basic risk communication to non-technical audiences	Detailed risk analysis communication to technical specialists
Risk compliance	Visualising compliance with well-defined risk criteria	Classifying risks in settings with unclear risk acceptance criteria
Risk ranking	Rough classification into a few categories	Precise risk ranking
Other	Initial risk screening	Resource allocation or detailed mitigation planning

3.4.2.2 Risk Matrix with Multiple Consequence Scales

Figure 4 Risk Matrix with Risk Tolerance Criteria.

> 1/10 yr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
< 1/10 yr to > 1/100 yr	ALARP	ALARP	Intolerable	Intolerable	Intolerable	Intolerable
< 1/100 yr to > 1/1,000 yr	Tolerable	ALARP	ALARP	Intolerable	Intolerable	Intolerable
< 1/1,000 yr to > 1/10,000 yr	Tolerable	Tolerable	ALARP	ALARP	Intolerable	Intolerable
< 1/10,000 yr to > 1/100,000 yr	Tolerable	Tolerable	Tolerable	ALARP	ALARP	Intolerable
< 1/100,000 yr to > 1/1,000,000 yr	Tolerable	Tolerable	Tolerable	Tolerable	ALARP	ALARP
< 1/1,000,000 yr to > 1/10,000,000 yr	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable	ALARP
> 1/10,000,000 yr	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable
Workplace Safety	< 1 first aid	< 1 recordable injury	< permanent disabling injury	< 1 fatality	< 10 fatalities	≥10 fatalities
Community Safety	< 1 complaint	< 1 first aid	< 1 medical treatment case	< permanent disabling injury	< 1 fatality	≥ 1 fatality
Environmental	< 1 complaint	< RQ released *and* < Local media coverage	< Enforcing action *and* < Regional media coverage *and* < Sustained local media coverage	< Compulsory shutdown *and* < National media coverage *and* < Sustained regional media coverage	< New reg's promulgated *and* < Global media coverage *and* < Sustained national media coverage	< New laws passed *and* < Sustained global media coverage
Financial	< $700	< $7,000	< $70,000	< $700,000	< $7,000,000	<$70,000,000

Note. From "Making sense of risk tolerance criteria," by M. S. Schmidt, 2016, *Journal of Loss Prevention in the Process Industries*, *41*, p. 353 (https://doi.org/10.1016/j.jlp.2015.12.005).

Description

This adaptation of the risk matrix incorporates multiple consequence scales within a single framework, allowing for the simultaneous assessment of risks across different impact dimensions. Rather than using a single measure of consequence (such as financial impact), this approach includes various consequence categories, each with its own scale, such as personnel safety, environmental damage, reputational harm, and financial loss.

A key characteristic is the alignment of impact categories across different consequence scales. For instance, the matrix might suggest that a fatality in the workplace is equivalent to a specific amount of financial loss or a particular level of environmental damage (e.g., contamination requiring years of remediation).

Theoretical Foundation

Like the traditional risk matrix, this adaptation is based on the risk concept of Consequences and Probability (C,P), whilst emphasising that consequences can be graded on different scales.

Scientific Gaps and Shortcomings

While this adaptation attempts to address the commensurability problem inherent in traditional risk matrices, it does not eliminate it entirely. Rather, it makes the equivalencies between different consequence scales transparent and explicit,. Schmidt (2016) outlines a methodical approach to this challenge, suggesting that consequence scales should be:

1. Divided uniformly into impact categories separated by orders of magnitude
2. Aligned with impact categories in other consequence vectors that are deemed equally severe
3. Associated with externally benchmarked tolerable frequencies

Practical Application

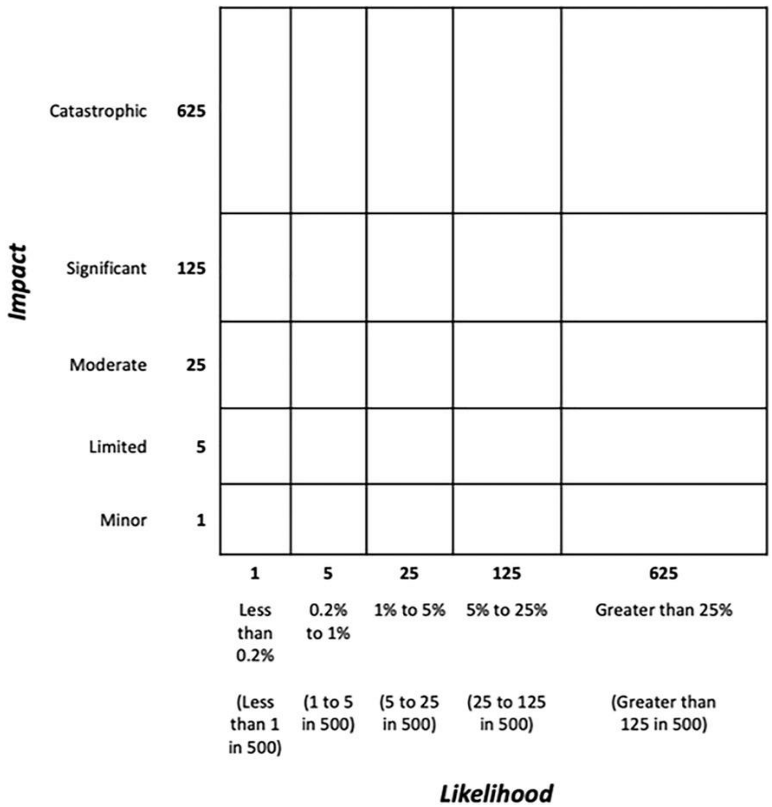
This risk matrix adaptation is most suitable for specific contexts and purposes, as outlined in the table below.

Table 8 Suitability of Risk matrix with multiple consequence scales

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Well-understood risks across multiple consequence domains	High uncertainty in the equivalence between different consequence types
Risk definition	Contexts where P, C definition is appropriate (large portfolios, narrow probability distributions)	Contexts where expected values misrepresent risk (e.g., highly skewed distributions)
Risk criteria	Organisations and or industries with well-established risk criteria across domains	Contexts where risk tolerances vary widely across consequence types
Variability and Correlation	Low variability in consequences and probability estimates, where expected values provide meaningful information. Positively correlated risks (probability and consequence increase together)	Highly variable and negatively correlated consequences and probability estimates
Purpose		
Communication	Basic risk communication to non-technical audiences	Detailed risk analysis communication to technical specialists
Risk compliance	Visualising compliance with well-defined risk criteria over different consequence categories	Classifying risks in settings with unclear risk compliance criteria
Risk ranking	Rough classification into a few categories	Precise risk ranking
Other	Initial risk screening	Resource allocation or detailed mitigation planning

3.4.2.3 Risk matrix with non-linear scaling and grids

Figure 5 Risk Matrix with Non-Linear Scaling and Grids



Note. From "How People Understand Risk Matrices, and How Matrix Design Can Improve their Use: Findings from Randomized Controlled Studies," by H. Sutherland, G. Recchia, S. Dryhurst, and A. L. J. Freeman, 2022, *Risk Analysis*, *42*(5), p. 1023 (https://doi.org/10.1111/risa.13822).

Description

While the traditional risk matrix and multiple consequence scales matrices use uniform grid layouts, the non-linear risk matrix adaptation introduces uneven spacing between grid lines to better represent logarithmic scales. In this adaptation, the distance between grid lines increases as one moves further along each axis, resulting in cells that grow larger toward the top-right corner of the matrix. This visual representation aims to emphasise that the differences between likelihood and impact categories increase exponentially rather than linearly.

The underlying concept is that when risk matrices represent logarithmic scales, the uniform grid layout of traditional matrices fails to visually communicate this non-linearity. The non-linear grid attempts to resolve this disparity between the visual representation and the mathematical reality. Additionally, this adaptation often incorporates non-linear scale labelling, using geometrically increasing values (e.g., 1, 5, 25, 125, 625) instead of sequential numbers (1, 2, 3, 4, 5). This further emphasises the exponentially increasing magnitudes.

Theoretical Foundation

The non-linear scaling and grid adaptation is grounded in cognitive psychology. Research suggests that humans process visual elements both through bottom-up perceptual mechanisms and top-down conceptual knowledge. When these processes align, comprehension improves; when they conflict, misinterpretation becomes more likely (Tzelgov et al., 1992).

Practical Application

The non-linear risk matrix adaptation is particularly valuable in contexts where risk factors span multiple orders of magnitude. Sutherland et al. (2022) found that the non-linear grid format ("logarithmic format") improved participants' ability to make risk comparisons compared to text-only presentations. More importantly, their research demonstrated that geometric scale labelling (using 1, 5, 25, 125, 625 instead of 1, 2, 3, 4, 5) resulted in improvements in risk comparison tasks, with a moderate effect size (f = 0.41).

Scientific Gaps and Shortcomings

The non-linear risk matrix has limitations similar to traditional matrices, such as issues with discretising continuous risk spaces and the risk of rank reversals (Cox, 2008). However, it presents unique challenges. Users may find the non-uniform grid less intuitive, hindering adoption. Sutherland et al. (2022) found participants preferred familiar formats, though this preference decreased with exposure. And whilst geometric scale labelling improved risk comparisons, it slightly decreased performance on basic knowledge questions (f = 0.06).

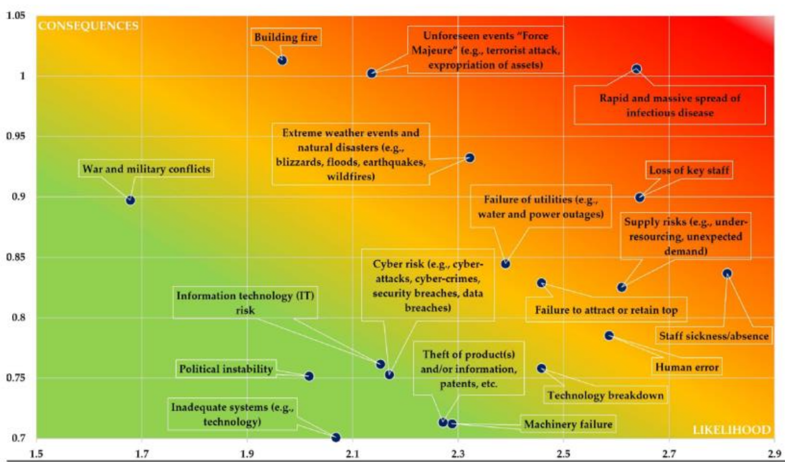
Despite these limitations, the non-linear risk matrix adaptation represents an improvement over standard risk matrices when the logarithmic relationships between risk categories are important. When implemented with geometric scale labelling and integrated information about what each category represents, this format has empirical support for enhancing risk comparison tasks compared to traditional approaches.

Table 9 Suitability of Risk matrix with non-linear scaling and grids

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Well-understood risks with low uncertainty in probability and consequence estimates	High uncertainty situations with limited data or knowledge
Risk definition	Contexts where a P, C definition is appropriate (large portfolios, narrow probability distributions)	Contexts where expected values misrepresent risk (e.g., highly skewed distributions)
Variability and Correlation	Low variability in consequences and probability estimates, where expected values provide meaningful information. Positively correlated risks (probability and consequence increase together)	Highly variable and negatively correlated consequences and probability estimates
Purpose		
Communication	Communicating where understanding of logarithmic relationships is important	Situations where the use of linear scaling is appropriate.
Risk compliance	Visualising compliance with well-defined risk criteria that have logarithmic scales	Classifying risks in settings with unclear risk compliance criteria
Risk ranking	Rough classification into a few categories where magnitude differences are important	Precise risk ranking within a single risk category
Other	Initial risk screening	Resource allocation or detailed mitigation planning

3.4.2.4 Heat map

Figure 6 Risk Heat Map



Note. From "Integrating Resilience into Risk Matrices: A Practical Approach to Risk Assessment with Empirical Analysis," by A. Vaezi, S. Jones, and A. Asgary, 2024, *Journal of Risk Analysis and Crisis Response*, *13*(4), p. 266 (https://doi.org/10.54560/jracr.v13i4.411).

Description

A risk heatmap is a representation of risk that uses colour gradients instead of discrete cells to indicate varying levels of risk. Unlike the traditional risk matrix with distinct, uniformly coloured cells, heatmaps utilise a continuous spectrum of colours to denote the transition between different risk levels. The intensity of colour typically increases with the severity of risk. This approach acknowledges that risk exists on a continuum rather than in discrete categories.

Theoretical Foundation

The risk heatmap is based on the same theoretical framework as the conventional risk matrix, using the risk concept of Consequence × Probability. Yet, it overcomes a key limitation of the traditional method: the segmentation of continuous risk variables.

From a cognitive perspective, heatmaps align better with how humans naturally perceive continuity in risk. The gradual transition between colours provides a more accurate representation of the continuous nature of risk, avoiding the abrupt transitions between risk categories that might not reflect reality (Entacher & Sander, 2018).

The theoretical justification for heatmaps can be traced to information visualisation principles that suggest continuous data should be represented continuously. This approach helps to overcome what Cox (2008) called the "range compression" problem in traditional risk matrices, where quantitatively different risks receive identical classifications because they fall within the same cell.

Scientific Gaps and Shortcomings

While risk heatmaps address some limitations of traditional risk matrices, they still have shortcomings. The selection of colour schemes can significantly impact how risk is perceived. Certain colour gradients might unintentionally emphasise or de-emphasise particular risk regions (Entacher & Sander, 2018). In addition to this, the colours of the heatmap are often not in congruence with the iso contours formed when a linear probability and consequence scale is used. Secondly, colour-based visualisations pose challenges for users with colour vision deficiencies. While traditional matrices can use patterns or textures to supplement colour coding, this becomes more complex with the continuous gradients used in heatmaps.

Practical Application

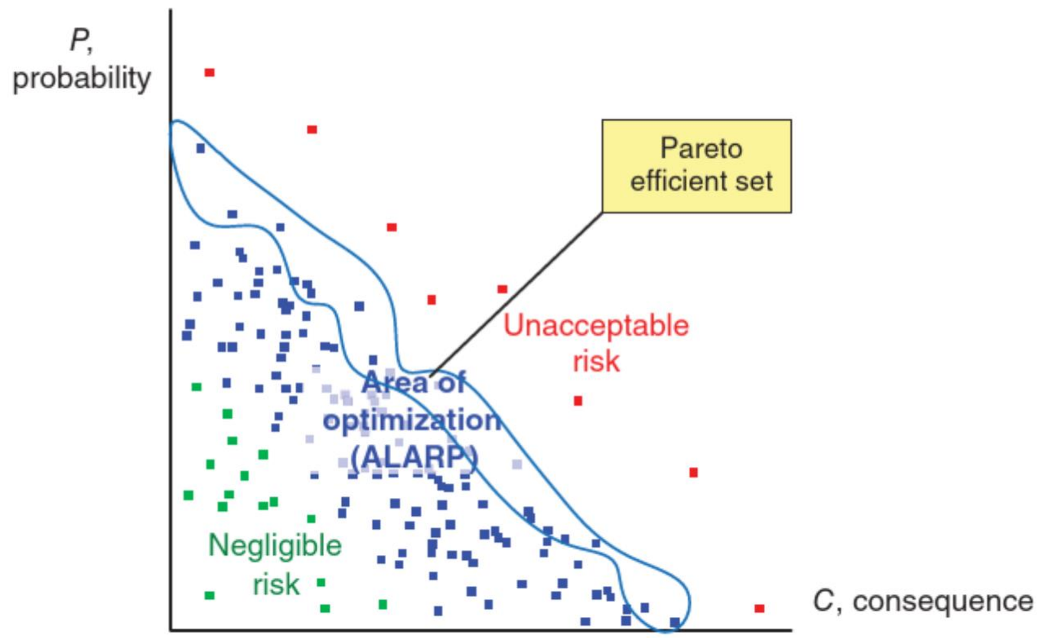
The continuous nature of heatmaps allows for more precise representation of incremental changes in risk profiles compared to discrete matrices, making them suited for time-series risk monitoring applications.

Table 10 Suitability of the risk heat map

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Weak to strong knowledge base, depending on the precision of the scaling used in the heatmap	
Risk definition	Contexts where P, C definition is appropriate (large portfolios, narrow probability distributions)	Contexts where expected values misrepresent risk (e.g., highly skewed distributions)
Variability and Correlation	Low variability in consequences and probability estimates, where expected values provide meaningful information. Positively correlated risks (probability and consequence increase together)	Highly variable and negatively correlated consequences and probability estimates
Purpose		
Communication	Visualising changes in risk profiles over time or across scenarios	Communicating compliance with risk criteria
Risk compliance	Unclear risk criteria	Compliance with clear risk criteria
Risk ranking	Precise ranking of risks, depending on the precision of the scales used	
Other	Subtle colour changes can be difficult to differentiate	

3.4.2.5 Scatter diagram

Figure 7 Scatter Diagram for the Presentation of Results of Quantitative Risk Analysis



Note. From "Qualitative Risk Analysis" (p. 472), by R. Tiusanen, C. Rollenhagen, S. O. Hansson, N. Moller, and J. E. Holmberg, in *Handbook of Safety Principles*, 2017, John Wiley & Sons, Inc. (https://doi.org/10.1002/9781119443070.ch21). Copyright 2017 by John Wiley & Sons, Inc.

Description

The scatter diagram represents a departure from traditional risk matrices by plotting individual risk events as points on a continuous coordinate system rather than categorising them into discrete grid cells. Each point's position precisely represents its specific probability and consequence values, preserving the exact quantitative relationships between different risk events that would otherwise be lost through categorical grouping.

Theoretical Foundation

This approach draws from basic principles of descriptive statistics, where scatter plots serve as a foundational tool for exploratory data analysis and model fitting. As a two-dimensional representation plotting probability against consequence, the scatter diagram can function independently of any risk formula. However, when risk contours are incorporated to show zones of equal risk, these typically follow the P×C risk concept used in traditional risk matrices.

Scientific Gaps and Shortcomings

Despite offering greater precision than traditional matrices, scatter diagrams present several limitations that restrict their practical utility. Most fundamentally, scatter diagrams function primarily as analytical instruments for data exploration rather than direct decision-making aids, requiring substantial quantitative data for both probability and consequence dimensions that may not be readily available in all contexts. Presenting stakeholders with a scatter plot without an additional interpretive framework would be inappropriate, as this does not provide adequate decision support.

The authors of the figure above describe how scatter diagrams can partially address resource allocation challenges by applying Pareto efficiency principles. As they noted in the Handbook of Safety Principles, "*a hazard is Pareto efficient (i.e., kind of highly critical) if there is no other hazard which has higher probability and higher consequence*," and decision-makers "*should first pay attention to the most critical (Pareto efficient) hazards"* (Tiusanen et al, 2017, p. 472). However, whilst scatter diagrams can inform resource allocation decisions more effectively than traditional matrices through this approach, they cannot fully optimise resource allocation without incorporating additional economic considerations. Effective resource allocation requires understanding not only the distribution of risks but also the costs of implementing risk reduction measures and their relative effectiveness, information that scatter diagrams alone cannot provide.

Practical Application

The scatter diagram approach proves particularly valuable as an analytical tool for resource allocation analysis and exploratory data analysis. When plotting multiple events and their associated hazards, scatter diagrams help visualise which hazards contribute to which risks, supporting initial decisions about prioritisation. This approach can partially address the 'knapsack problem' of resource allocation by identifying Pareto-efficient risks—those where no other hazard exhibits both higher probability and higher consequence (Tiusanen et al., 2017).

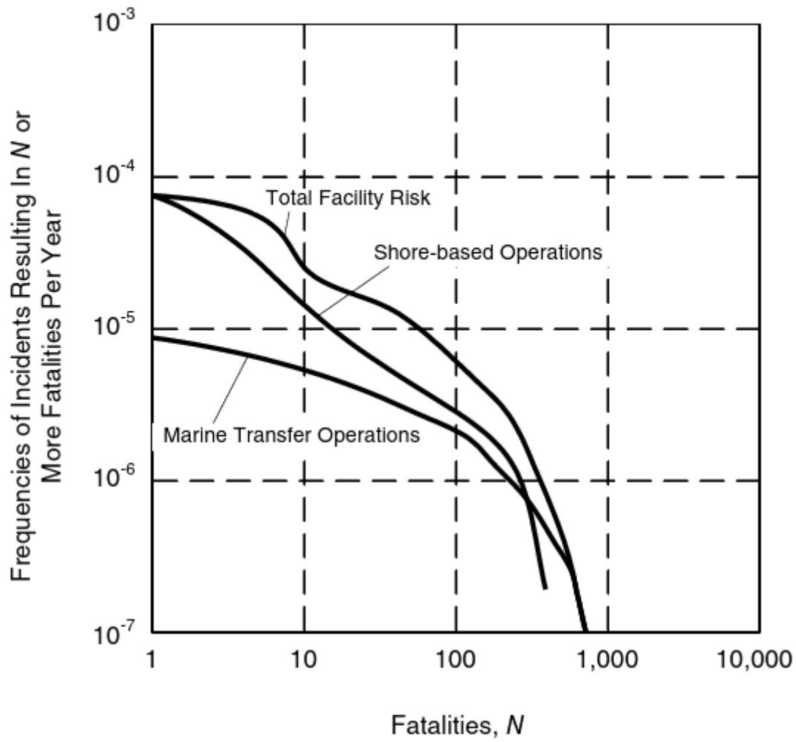
However, scatter diagrams represent an intermediate analytical step rather than a final decision-making tool. Whilst they provide superior information compared to traditional risk matrices for resource allocation decisions, full optimisation requires additional consideration of intervention costs and risk reduction effectiveness.

Table 11 Suitability of the scatter diagram

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Strong knowledge base with sufficient quantitative data to reliably position risks as precise points	Weak knowledge base where only qualitative or categorical assessments are possible
Risk definition	Risk perspectives based on P, C with continuous probability and consequence scales	Risk definitions emphasising uncertainty
Risk criteria	Risk criteria can be visualised by colouring the plotted risks	
Variability and correlation	Low variability in consequences and probability estimates, where expected values provide meaningful information. Positively correlated risks (probability and consequence increase together)	Highly variable and negatively correlated consequences and probability estimates
Purpose		
Communication	Technical audiences comfortable with quantitative data interpretation	Non-technical stakeholders requiring simple categorical risk messages
Risk compliance	Suitable when thresholds are available	
Risk ranking	Quick screening	Detailed resource allocation

3.4.2.6 FN-curves

Figure 8 FN-Curve



Note. From *Guidelines for Chemical Process Quantitative Risk Analysis, 2nd Edition*, by Center for Chemical Process Safety, 2000, American Institute of Chemical Engineers. Copyright 2000 by American Institute of Chemical Engineers

Description

FN-curves, or Frequency-Number curves plot the frequency (F) of exceeding a specified number (N) of fatalities or other consequences against that number. While differing substantially from conventional risk matrices in appearance, FN-curves align with the broader definition of PCDs as they map risks along two dimensions: frequency and consequence magnitude. As discussed by Ale et al. (2015), FN-curves have historical significance as foundational elements in the development of probability-consequence diagrams. Therefore, this thesis would be incomplete without referencing FN-curves.

FN-curves typically employ logarithmic scales on both axes, presenting a continuous line that shows the relationship between accident frequency and consequence severity across the entire spectrum of potential outcomes. The curve represents the cumulative complementary distribution function, showing for each consequence level N the frequency F of all accidents with consequences equal to or greater than N.

Theoretical Foundation

FN-curves are grounded in a mathematical framework designed to address societal risk assessment rather than individual risk. Their theoretical foundation rests on continuous risk representation, which eliminates the "range compression" problem identified by Cox (2008) where quantitatively different risks receive identical classifications. The logarithmic scaling reflects the wide range of frequencies and consequences requiring visualisation, from frequent minor events to rare catastrophic ones.

FN-curves can incorporate risk acceptance criteria lines that define boundaries between acceptable, tolerable (ALARP), and unacceptable risk regions. These criteria often reflect societal risk aversion, as they employ slopes steeper than -1, acknowledging a societal preference for avoiding large-scale accidents. The mathematical structure also allows aggregation of risks from multiple sources into a single comprehensive curve.

Scientific Gaps and Shortcomings

The concept of cumulative frequency of exceedance proves challenging for non-technical stakeholders to understand, potentially limiting its effectiveness as a communication tool. Most implementations focus on a single consequence measure (typically fatalities), creating challenges when multiple consequence types require consideration. Furthermore, FN-curves require substantial data on both event frequencies and consequence distributions, which can be complicated and time-intensive to obtain.

Practical Application

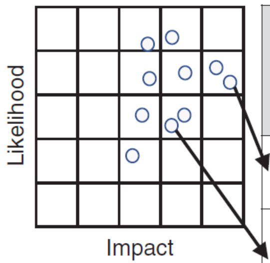
FN-curves prove valuable for major hazard facilities, transportation of dangerous goods, and land use planning around hazardous installations. They excel in regulatory contexts where societal risk criteria are explicitly defined in FN-curve terms, such as in the Netherlands and United Kingdom.

Table 12 Suitability of FN diagram

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Medium to strong knowledge base with comprehensive data or models to estimate consequence distributions	Limited data contexts where consequence distributions cannot be reliably estimated
Risk definition	Contexts where the relationship between consequence and probability (C,P) are relevant, particularly for cumulative frequency distributions.	
Risk criteria	Well-established FN-criteria and regulatory frameworks explicitly referencing societal risk limits	Regulatory environments based solely on individual risk or simple categorical thresholds
Consequence domains	Single consequence domain (typically fatalities) with potential for multiple casualties in single events	Multiple different consequence types requiring simultaneous consideration
Variability and correlation	Various correlation patterns, positive and negative correlations between frequency and consequences (in this case, fatalities)	
Purpose		
Communication	Technical audiences with expertise in risk assessment and familiarity with cumulative frequency concepts	Non-technical stakeholders requiring intuitive risk communication
Risk compliance	Regulatory compliance where societal risk criteria are explicitly defined in terms of FN-curves	Simple compliance decisions not based on FN-curves
Risk ranking	Comprehensive comparison for major hazard assessment	Operational decision-making requiring quick, simple risk prioritisation
Other	Major hazard facilities, chemical processing, transportation of dangerous goods, land use planning	Day-to-day operational risk management, routine compliance checks

3.4.2.7 Risk Matrix with Confidence Intervals

Figure 9 Risk Matrix with Confidence Intervals for the Consequences



Risk Name	Prob per year	Impact 90% Confidence Interval	
		Lower Bound	Upper Bound
Breach of customer database			
Accident at factory resulting in shutdown			
Loss of main supplier			
Product recall			

Note. From *The Failure of Risk Management: Why It's Broken and How to Fix It* (2nd ed., p. 281), by D. W. Hubbard, 2020, Wiley. Copyright 2020 by John Wiley & Sons, Inc.

Description

The risk matrix with confidence intervals enhances traditional risk matrices by incorporating uncertainty around consequence estimates. Rather than presenting risk as a single point estimate based on the product of consequence and likelihood, this adaptation characterises risk as a distribution by providing both an expected value and a 90% confidence interval for the expected consequences.

This approach recognises that consequence estimates contain inherent uncertainties stemming from incomplete knowledge, limited data, measurement errors, or modelling assumptions. The confidence intervals provide decision-makers with a visual representation of the range within which the true risk value is likely to fall, given the available information.

Theoretical Foundation

This adaptation is grounded in statistical theory and uncertainty analysis, maintaining the basic risk concept of Consequences × Probability while acknowledging that risk assessments contain uncertainty stemming from incomplete knowledge, limited data or imperfect models. The approach uses statistical methods to construct confidence intervals that account for these uncertainties.

Scientific Gaps and Shortcomings

Despite its improvements, the confidence interval adaptation presents several limitations. The visual representation adds complexity, making interpretation difficult for non-technical stakeholders. When multiple risks with confidence intervals are plotted, overlapping intervals complicate comparison. While the confidence interval provides more information on the uncertainties associated with the risk level, many aspects remain undescribed, such as the uncertainties related to the probability estimate or the information on which the consequence and probability estimates are built.

Practical Application

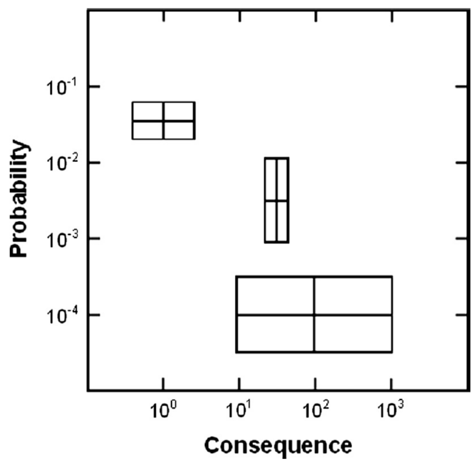
This visualisation is particularly helpful when there is high variance in an event's potential consequences. It helps decision-makers understand the range of possible outcomes rather than focusing solely on the expected value. It is most appropriate for audiences familiar with statistical concepts.

Table 13 Suitability of the risk matrix with confidence intervals

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	A good to weak knowledge base, depending on the effect of uncertainties, as uncertainties are only represented about the consequences estimates.	Highly uncertain risks
Risk definition	CxP, as well as risk definitions that capture an element of uncertainty about the consequence estimates.	Risk definitions that give much weight to the uncertainty aspects of risks
Risk criteria	Risk criteria can be added. But compliance can be difficult to determine if the consequence scale encompasses the thresholds.	
Variability	Low variability in probability estimates and high variability in consequence estimates. Positively correlated risks	High variability in probability estimates. Negatively correlated risks
Purpose		
Communication	Audiences familiar with statistics and situations requiring nuanced communication of consequence estimates.	Non-technical audiences
Risk compliance	Regulatory environments that recognise and value uncertainty quantification.	Compliance regimes requiring definitive binary classifications (pass/fail)
Risk Ranking	Decision contexts valuing a nuanced understanding of consequence uncertainty	Situations requiring rapid, unambiguous risk prioritisation
Other		

3.4.2.8 PCD with uncertainty boxes

Figure 10 Probability-Consequence Diagram with Uncertainty Boxes



Note. from "Recommendations on the use and design of risk matrices," by N. J. Duijm, 2015, *Safety Science*, *76*, p. 21-31 (https://doi.org/10.1016/j.ssci.2015.02.014).

Description

The Probability-Consequence Diagram (PCD) with uncertainty boxes enhances traditional risk matrices by visualising risks as rectangular areas rather than single points. Each box has a central point indicating the expected probability and consequence values, while its vertical and horizontal dimensions represent the uncertainty ranges within which the "true" risk level is believed to lie. The horizontal dimension of each box represents uncertainty in consequence assessment, while the vertical dimension shows uncertainty in probability estimation. Larger boxes indicate lower confidence in the risk assessment, helping to prevent the false impression of precision that traditional risk matrices often convey to decision-makers (Duijm, 2015).

Theoretical Foundation

This adaptation is grounded in statistical theory while building upon the risk definition of Consequences and Probabilities (C,P). Uncertainty boxes represent interval estimates that may be derived through expert judgement, uncertainty analysis, or statistical methods. The box shape provides valuable information about where uncertainty primarily lies—in consequence estimation (wide box), probability estimation (tall box), or both dimensions equally.

Scientific Gaps and Shortcomings

Despite its advantages, this approach has several limitations. Uncertainty boxes can be difficult for non-technical audiences to interpret, and there is a lack of standardisation in determining box boundaries. While uncertainty boxes address probability and consequence uncertainty, they don't explicitly represent uncertainty related to the strength of evidence underpinning the assessment. Visual clutter may hinder understanding when several risks accompanied by uncertainty boxes are shown at once. Risk acceptance becomes ambiguous when uncertainty boxes span multiple risk categories, complicating decision-making.

Practical Application

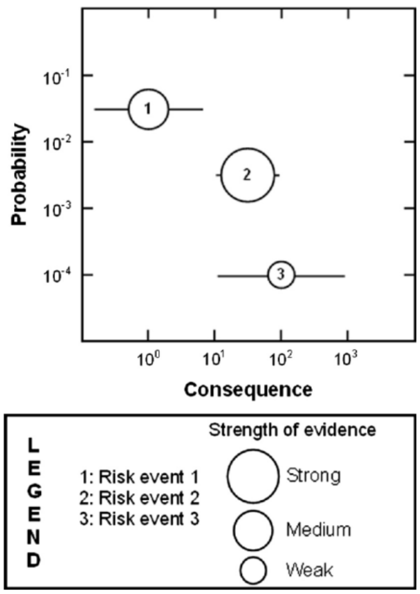
This approach is particularly valuable in contexts with significant uncertainty requiring transparent communication. It suits scenarios with moderate uncertainty where sufficient knowledge exists to estimate uncertainty bounds but not enough for precise point estimates. It is appropriate when uncertainty bounds are meaningful and can be reasonably estimated from either frequentist probabilities and consequences or expert judgement.

Table 14 Suitability of the PCD with uncertainty boxes:

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Contexts with varying knowledge bases	
Risk definition	Risk perspectives based on probability and consequence (P,C) with acknowledgement of uncertainties related to these estimates.	Risk defined as an expected value of consequences and probabilities (CxP)
Risk criteria	Risk criteria can be added. But compliance can be difficult to determine if the confidence intervals encompass the thresholds.	
Variability and Correlation	High variability in consequences and probability estimates, where expected values provide insufficient information. Positive or negative correlations between consequences and probabilities.	Low variability in consequences and probability estimates, where expected values are sufficient.
Purpose		
Communication	Technical audiences who need to understand assessment limitations. Communicating where uncertainty reduction efforts should focus.	Visualising large numbers of risks at the same time
Risk compliance	Regulatory frameworks that recognise uncertainty ranges and allow for the interpretation of boundary cases	Compliance regimes requiring definitive pass/fail determinations
Risk ranking	Comparing risks where uncertainty differs significantly between options, evaluating whether uncertainty itself should influence prioritisation	Quick screening of numerous risks
Other		

3.4.2.9 Bubble diagram

Figure 11 2-Dimensional Probability-Consequence Diagram with Prediction Intervals and Strength of Evidence Assessment (PCD-PSEA)



Note. from "On the assessment of uncertainty in risk diagrams," by F. Goerlandt and G. Reniers, 2016, *Safety Science*, *84*, p. 67 (https://doi.org/10.1016/j.ssci.2015.12.001), and "Safety oriented bubble diagrams vs: risk plots based on prediction intervals and strength-of-knowledge assessments. Which one to use as an alternative to risk matrices?," by E. Abrahamsen, Ø. Amundrud, T. Aven, and A. Gelyani, 2014, *Int. J. Bus. Continuity Risk Manag.*, *5*, p. 197 (https://doi.org/10.1504/IJBCRM.2014.066159).

Description

The bubble diagram represents an adaptation of the risk matrix with confidence intervals that incorporates a strength of evidence assessment. Like conventional risk matrices, it plots risk events on a two-dimensional grid with probability on one axis and consequence on the other. However, it introduces a third dimension—the strength of evidence associated with the risk assessment, represented by the size of the bubble that marks each risk event. Larger bubbles indicate lower strength of evidence, providing a visual cue of the confidence level of each risk assessment.

Theoretical Foundation

The bubble diagram is grounded in uncertainty-based risk perspectives that recognise the limitations of describing risk solely through probabilities and expected consequences. The strength of evidence dimension is typically assessed using qualitative categories (low, medium, high) based on criteria including the understanding of phenomena, reasonableness of assumptions, data availability, and expert consensus.

Scientific Gaps and Shortcomings

Despite representing a significant advancement in risk visualisation, bubble diagrams have several limitations. The qualitative assessment of uncertainty relies on subjective judgment and may be inconsistently applied. By condensing uncertainty into just three categories, bubble diagrams may oversimplify complex uncertainty profiles.

Practical Application

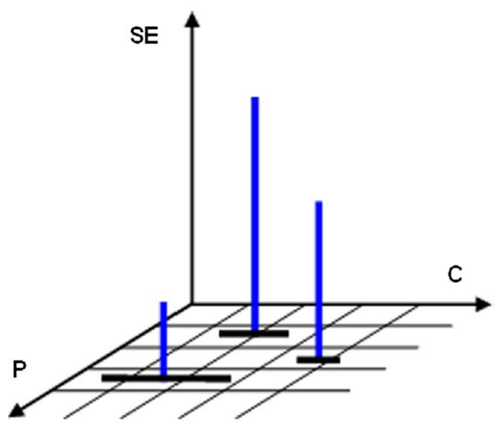
Bubble diagrams are particularly well-suited for risk problems where extra attention should be given to uncertainties. Although more complicated than a traditional risk matrix, bubble diagrams are still fairly easy to understand for a non-technical audience.

Table 15 Suitability of the bubble diagram

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Mixed knowledge base where strength of evidence varies across risks	Contexts where all risks have uniformly strong or uniformly weak evidence
Risk definition	Risk perspectives emphasising an element of uncertainty	Traditional P×C definitions without consideration of uncertainties
Risk criteria	Contexts where risk acceptability depends on both risk magnitude and confidence in assessment	Compliance based solely on probability and consequence
Variability and correlation	High variability in consequences estimates, where expected values provide insufficient information. Positive or negative correlations between consequences and probabilities.	Low variability in consequences and probability estimates, where expected values are sufficient.
Purpose		
Communication	Mixed audiences, including both technical and non-technical stakeholders; contexts requiring intuitive uncertainty visualisation	Highly technical contexts requiring detailed uncertainty characterisation
Risk compliance	Flexible regulatory frameworks that consider strength of knowledge in risk acceptability	Rigid compliance regimes based solely on probability-consequence thresholds
Risk ranking	Prioritisation considering both risk level and assessment confidence; identifying risks requiring further investigation	Situations requiring precise quantitative ranking without uncertainty considerations
Other		

3.4.2.10 Risk plot / Three-dimensional PCD

Figure 12 Risk Plot / Three-Dimensional Probability-Consequence Diagram



Note. Adapted from "Practical implications of the new risk perspectives," by T. Aven, 2013, *Reliability Engineering & System Safety*, *115*, pp. 136-145 (https://doi.org/https://doi.org/10.1016/j.ress.2013.02.020).

Description

The Risk plot or Three-dimensional Probability-Consequence Diagram (3D PCD) represents an extension of the bubble diagram concept, transforming the third dimension (represented by bubble size) into a vertical axis (Abrahamsen et al., 2014; Aven, 2013). While bubble diagrams represent strength of evidence through varying bubble sizes on a flat plane, the 3D PCD plots risk events as bars in a three-dimensional space, with the z-axis directly representing the strength of evidence or knowledge underlying the assessment.

Theoretical Foundation

Like the bubble diagram, the 3D PCD builds upon uncertainty-based risk perspectives that recognise the limitations of traditional probability and consequence frameworks. The primary distinction lies in the representation of uncertainty rather than in the risk concept. The 3D PCD maintains the same approach to categorising strength of evidence (typically classifying based on data quality, assumptions, expert consensus, and model reliability), but presents this information through spatial positioning rather than graphical attributes.

Scientific Gaps and Shortcomings

The 3D PCD shares many of the same limitations as bubble diagrams regarding the subjectivity of evidence strength assessment and potential oversimplification of complex uncertainty profiles. Additionally, three-dimensional visualisations presented on two-dimensional media (printed reports) create interpretation difficulties, as users may struggle to perceive spatial relationships and depth cues accurately.

Practical Application

The 3D PCD is most suitable in contexts where bubble diagrams would be appropriate but where additional spatial representation might offer advantages. In particular, it may be valuable when:

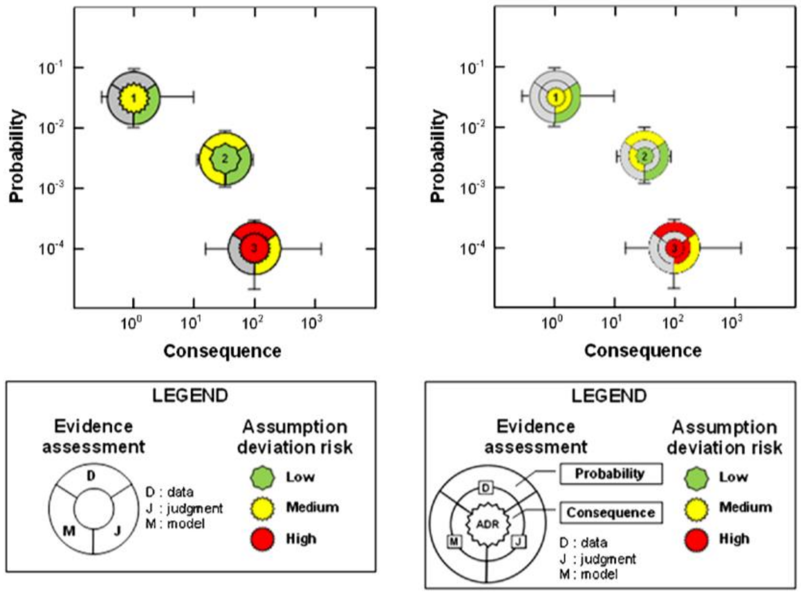
1. **Visualisation tools are available**: In organisations with access to data visualisation software, such as risk management dashboards.
2. **Technical audiences**: When communicating with stakeholders who are comfortable interpreting three-dimensional data visualisations.
3. **Precise mapping of Strength of Knowledge is important**, As the 3D PCD offers a more precise mapping of SoK than a bubble diagram.

Table 16 Suitability of the risk plot

Factor	**Suitable for**	**Unsuitable for**
Risk Problem Characteristics		
Knowledge base	Mixed knowledge base where strength of evidence varies significantly across different risks	Contexts where all risks have uniformly strong or uniformly weak evidence
Risk definition	Risk perspectives emphasising uncertainty	Traditional P×C definitions without consideration of uncertainty aspects
Risk criteria	Contexts where risk acceptability depends on risk magnitude, probability, and strength of evidence	Settings requiring compliance based solely on probability and consequence thresholds
Variability and correlation	Situations with variable SoK and consequence levels across risks	Homogeneous risk sets where 2D representation suffices; contexts where 3D adds complexity without benefit
Purpose		
Communication	Communicating risks to technical audiences comfortable with three-dimensional data interpretation, interactive presentation environments and confidence intervals	Non-technical stakeholders; static presentation formats
Risk compliance	Regulatory frameworks explicitly incorporating strength of evidence in compliance determination	Compliance regimes based solely on two-dimensional risk assessment
Risk ranking	Complex prioritisation requiring simultaneous consideration of probability, consequence and SoK	Quick screening or situations where 3D complexity hinders rather than helps decision-making
Other	Organisations with advanced visualisation capabilities, contexts where spatial representation enhances understanding	Resource-constrained environments, situations where simpler alternatives (e.g., bubble diagrams) suffice

3.4.2.11 PCD with strength of evidence and assumption deviation risk assessment

Figure 13 Probability-Consequence Diagram with Strength of Evidence and Assumption Deviation Risk Assessment



Note. From "On the assessment of uncertainty in risk diagrams" (Figure 7, p. 16), by F. Goerlandt and G. Reniers, 2016, *Safety Science*, *84*, 67-77 (https://doi.org/10.1016/j.ssci.2015.12.001).

Description

The Probability-Consequence Diagram with Strength of Evidence and Deviation Risk Assessment (PCD-SEDR) represents an evolution of uncertainty-conscious risk visualisation approaches. This adaptation combines multiple uncertainty dimensions within a single framework, incorporating both the strength of evidence assessment (similar to bubble diagrams) and an explicit assessment of assumption deviation risks.

In this visualisation, risk events are typically represented using segmented bubbles positioned on a standard probability-consequence grid. The segments of each bubble are colour-coded to represent the strength of evidence in different categories (e.g., data quality, model reliability, expert judgement), while a Tukey boxplot indicates the potential for deviations from expected outcomes due to assumption uncertainties. This comprehensive approach attempts to present a more nuanced picture of risk by distinguishing between different sources of uncertainty.

Theoretical Foundation

The PCD-SEDR builds upon the same uncertainty-based risk perspectives as bubble diagrams and 3D PCDs, but with an additional theoretical layer addressing different parts of the strength of evidence. This adaptation recognises that beyond general evidence strength, the specific assumptions underlying a risk assessment carry their own vulnerability to deviation.

The assumption deviation risk component draws from Aven's (2013) work, which emphasises that even assessments based on seemingly strong evidence may be vulnerable to significant deviations if they rely on critical assumptions that could prove incorrect. This theoretical refinement acknowledges that uncertainty exists in multiple forms and that different types of uncertainty may require different risk management responses.

Scientific Gaps and Shortcomings

While offering the most comprehensive approach to uncertainty visualisation, the PCD-SEDR presents significant practical challenges:

1. **Visual complexity**: The incorporation of multiple uncertainty dimensions creates a visually dense representation that can be difficult to interpret, particularly for non-specialist audiences.

2. **Assessment complexity**: The approach requires separate assessments of evidence strength across multiple categories and assumption deviation risks.

3. **Implementation barriers**: Few organisations have established protocols for the systematic assessment of assumption deviation risks, making consistent implementation difficult.

Practical Application

The PCD-SEDR is most suitable for highly specialised contexts where detailed uncertainty characterisation justifies the additional complexity. For most practical applications, simpler approaches like standard bubble diagrams may offer a more accessible alternative that communicates key uncertainty information without overwhelming users with visual complexity.

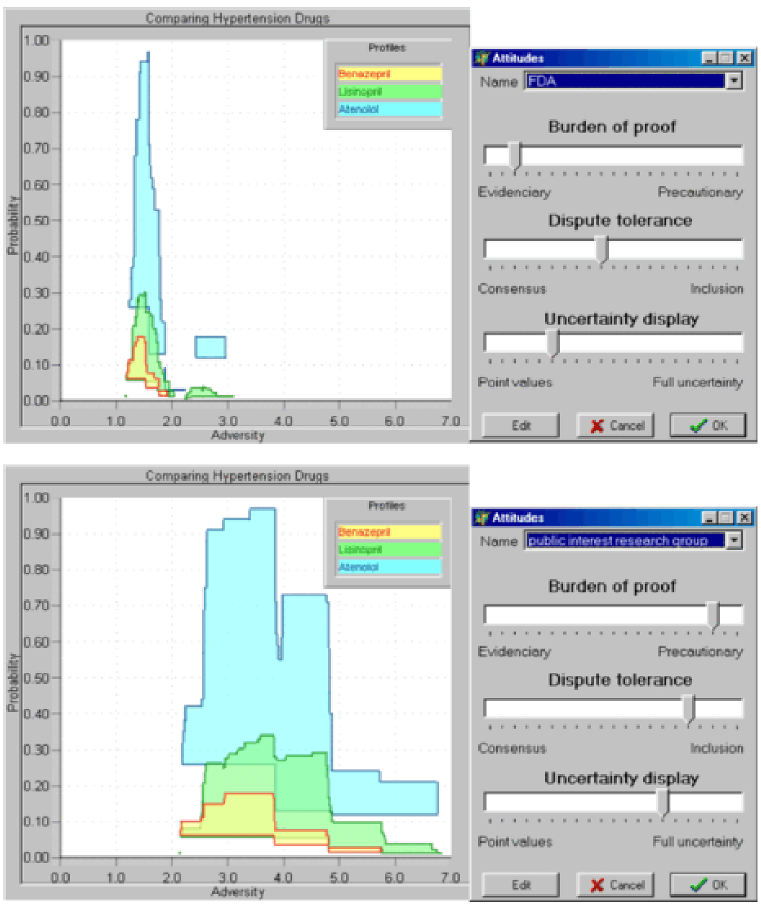
Table 17 Suitability of the PCD with Strength of Evidence and Deviation Risk Assessment

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Weak to mixed knowledge base, where strength of evidence varies significantly, and assumption vulnerability is a concern	Strong, uniform knowledge base where detailed uncertainty characterisation is unnecessary
Risk definition	Risk perspectives emphasising (A,C,U) with multiple uncertainty dimensions requiring explicit representation	Traditional P×C definitions without consideration of knowledge quality or assumption vulnerability
Risk criteria	Contexts where risk acceptability depends on risk magnitude, probability, strength of evidence, and assumption robustness	Settings requiring simple compliance based solely on probability and consequence thresholds
Consequence domains	Complex risk scenarios where multiple evidence types and assumption dependencies exist	Simple, well-understood risks with uniform evidence quality
Variability and correlation	High variability in both risk outcomes and uncertainty levels; contexts where assumption deviation risks vary significantly	Homogeneous risk sets where simpler uncertainty visualisation suffices
Purpose		
Communication	Highly specialised expert teams comfortable with multidimensional uncertainty interpretation	Non-technical stakeholders or contexts requiring accessible risk communication
Risk compliance	Advanced regulatory frameworks explicitly incorporating multiple uncertainty dimensions in compliance determination	Traditional compliance regimes based on straightforward risk assessment
Risk ranking	Complex prioritisation requiring simultaneous consideration of probability, consequence, evidence strength, and assumption vulnerability	Quick screening or situations where visual complexity hinders decision-making
Other	Critical safety applications with severe failure consequences; mature risk management cultures with established protocols	Resource-constrained environments, organisations without experience in uncertainty assessment

3.4.2.12 Risk attitude adaptive risk matrix

Figure 14 Risk Attitude Adaptive Risk Matrix

A
B



Note. From "A Frequency/Consequence-based Technique for Visualizing and Communicating Uncertainty and Perception of Risk," by D. Slavin, W. T. Tucker, S. Ferson, and A. M. Finkel, 2008, *Annals of the New York Academy of Sciences*, *1128*(1), p. 63 (https://doi.org/10.1196/annals.1399.008). Copyright 2008 by New York Academy of Sciences.

Description

The Risk Attitude Adaptive Risk Matrix represents an approach to risk visualisation that explicitly accounts for the subjective attitudes and preferences of different stakeholders towards risk. Unlike traditional risk matrices, which apply uniform risk categorisation across all users, this adaptation recognises that different individuals and groups may have varying risk tolerances, precautionary preferences, and interpretations of uncertainty.

The adaptation is exemplified by the work of Slavin et al. (2008), who developed a frequency/consequence-based technique that incorporates three key attitude parameters: Burden of Proof, Dispute Tolerance, and Uncertainty Display. These parameters are implemented through interactive sliders that allow users to adjust their risk visualisation based on their specific attitudes toward uncertainty and risk.

The Burden of Proof parameter quantifies the perceiver's attitude toward the meaning of absence of evidence, ranging from "safe until proven otherwise" to "harmful until proven safe."

Dispute Tolerance reflects how individuals interpret disagreements between different experts or stakeholders about the same risk. At one extreme, users may prefer to seek consensus by averaging expert opinions or dismissing outlying views. At the other extreme, users may wish to preserve and display the full diversity of expert judgements, showing where professionals disagree about severity assessments.

Uncertainty Display gauges the importance placed on inherent uncertainty in the underlying data and phenomena themselves. This ranges from preferring deterministic point estimates that hide data limitations to fully acknowledging uncertain bounds that reflect measurement errors, natural variability, and incomplete knowledge about the risk scenario.

Theoretical Foundation

The Risk Attitude Adaptive Risk Matrix builds upon research in risk perception psychology, particularly the psychometric paradigm developed by Slovic and colleagues (Fischhoff et al., 1978; Slovic, 1987). This theoretical foundation recognises that expert risk assessments and lay assessments often differ, and that these differences stem from varying mental models of risk rather than misunderstanding.

The adaptation draws from the Carnegie Mellon approach to risk communication, which emphasises the importance of mapping and contrasting different mental models of risk held by various stakeholders (Morgan, 2002). It acknowledges that risk perception varies socioculturally and that different individuals may employ fundamentally different conceptual frameworks when evaluating risk.

The theoretical justification rests on the premise that there is no single correct way to perceive risk, and that multiple valid perspectives can coexist based on different value systems and interpretations of uncertainty. This approach aligns with contemporary risk governance frameworks that emphasise stakeholder engagement.

Scientific Gaps and Shortcomings

The most significant challenge concerns the empirical validation of the approach. The authors acknowledge that research and data collection would be needed to accurately quantify attitudes toward uncertainty expressed by different individuals and groups. Their examples of how different stakeholder groups might set attitude parameters are based on stereotypes rather than empirical data about actual stakeholder preferences.

Attitude quantification presents another fundamental challenge. Converting psychological constructs into numerical parameters through three-slider interfaces inevitably involves oversimplification.

The implementation complexity, is evident in this visualisation. Users must simultaneously understand and adjust concepts like burden of proof and dispute tolerance, which may overwhelm non-technical stakeholders. It can also be time extensive to gather all the relevant data in order to map out the perspectives (Morgan, 2002).

Finally, the contextual sensitivity of the approach raises questions about consistency across applications. The same risk data can produce markedly different visualisations depending on stakeholder attitudes, which may complicate comparability and standardisation efforts.

Practical Application

The Risk Attitude Adaptive Risk Matrix is most valuable in contexts characterised by significant stakeholder diversity and high levels of controversy or disagreement about risk acceptability. It is of particular value when used as a tool to visualise how different groups have varying perspectives on uncertainty and precaution, and how this leads to varying levels of risk based on the same data.

Beyond its specific application, this adaptive matrix represents a methodological innovation worthy of broader consideration. From all the literature examined in this study, this was the only PCD adaptation that employed an adaptive approach to risk visualisation, which is a logical next step as risk communication moves more towards the digital space.

Adaptive risk matrices can have significant benefits for risk analysts. Enabling them to generate different versions tailored to specific audiences quickly. For instance, analysts could add elements that are important to particular stakeholder groups, adjust complexity levels based on technical expertise, or emphasise different uncertainty dimensions depending on audience needs. Such adaptability could enhance the effectiveness of risk communication by ensuring that visualisations match both the characteristics of the risk problem and the specific needs and capabilities of the intended audience.

Table 18 Risk Attitude Adaptive Risk Matrix

Factor	Suitable for	Unsuitable for
Risk Problem Characteristics		
Knowledge base	Moderate to weak knowledge base where uncertainty attitudes matter significantly	Strong knowledge base with clear, unambiguous data
Risk definition	Risk perspectives that acknowledge subjectivity and uncertainties	Technical risk assessments
Risk criteria	Risk criteria could be plotted as an additional layer, although it would make the graph more cluttered	
Variability and correlation	Situations with variable SoK and consequence levels across risks	Homogeneous risk sets where 2D representation suffices; contexts where 3D adds complexity without benefit
Purpose		
Communication	Facilitating dialogue between groups with different risk attitudes and values	Simple risk communication to technical audiences
Risk compliance	Generally not suited for compliance with risk criteria	
Risk Ranking	Comparing risks and the related stakeholder perceptions	Quick screening or situations where a standardised ranking suffices
Other	An extensive stakeholder analysis is necessary to gather all the required data.	

3.5 Conclusion

This scoping review has identified twelve distinct PCD adaptations across the literature, demonstrating a field where scholars share a common theoretical understanding of traditional risk matrix limitations whilst pursuing diverse methodological solutions. The analysis reveals that researchers have systematically developed these adaptations to address well-documented weaknesses around uncertainty representation and mathematical limitations.

Most research focuses on industry-specific applications rather than developing general frameworks for PCD design and selection. Cox's (2008) work continues to provide the primary theoretical foundation, with subsequent studies largely building upon his axioms to evaluate new adaptations (Bao et al., 2017; Lane & Hrudey, 2023; Levine, 2012; Li et al., 2018). Notably, empirical research on PCD effectiveness remains sparse, with Sutherland et al. (2022) and Proto (2023) being among the few empirical, quantitative studies that examine the performance of different PCD designs in practice.

The twelve adaptations identified reveal a clear progression from simple visualisations towards more sophisticated representations. These newer approaches explicitly incorporate uncertainty through multiple dimensions, such as strength of evidence assessments and assumption deviation risks. This development reflects contemporary risk definitions that extend beyond traditional probability-consequence frameworks.

However, this progression creates tension. While more complex adaptations offer greater theoretical rigour and a more comprehensive representation of uncertainty, they also become more challenging to implement and interpret. Simple adaptations, such as traditional risk matrices, lack academic rigour but remain accessible to decision makers. Conversely, sophisticated approaches like PCDs, which use the strength of evidence and confidence intervals for probability and consequence estimates, provide a comprehensive characterisation of uncertainty but may overwhelm users with (visual) complexity.

This tension highlights the need for systematic guidance in selecting suitable PCD adaptations that align with contemporary risk science. The absence of such guidance in the literature represents a significant gap, as practitioners currently select visualisation methods based on organisational habits or software availability rather than methodological suitability. This gap provides the rationale for developing the framework presented in the subsequent chapter, which aims to bridge the divide between theoretical advancement and the practical application of PCDs.

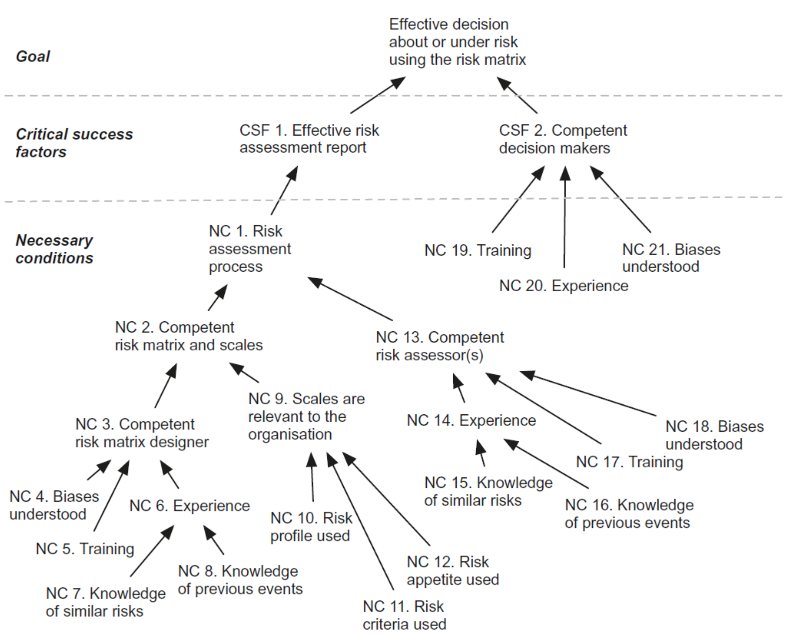
4. Framework design

The previous chapters have mapped the PCD adaptations found in the literature, describing the scientific foundation and the strengths and weaknesses of each adaptation. One step remains to be taken in order to put this knowledge into practice: developing a framework that guides a risk analyst in the selection of the most appropriate PCD adaptation for a certain risk problem.

Without systematic guidance, the selection of risk matrix adaptations often defaults to organisational habits, software availability, or personal preference rather than matching the adaptation's capabilities to the specific characteristics of a risk problem. This can lead to inappropriate visualisations that contribute little or, in the worst case, lead to worse than random decision making (Cox, 2008).

Currently, the literature offers limited guidance on selecting appropriate risk matrix adaptations systematically. In the scoping review conducted for this thesis, Peace (2017) stood out for identifying necessary conditions and critical success factors for effective decision-making using a risk matrix. See figure 8. Although these necessary conditions are relevant for effective risk assessment using risk matrices, Peace's framework does not address the fact that risk problems vary in their characteristics. And that different risk problems call for different diagrams. The current framework can therefore best be used in addition to Peace’s framework.

Figure 15 Goal Tree for Successful Design and Use of a Risk Matrix.



Note. From "The risk matrix: Uncertain results?," by C. Peace, 2017, *Policy and Practice in Health and Safety*, *15*(2), p. 144 (https://doi.org/10.1080/14773996.2017.1348571).

4.1 PCD Selection Framework

Tables 1 and 2 present the Risk Matrix Selection Framework that forms the central contribution of this thesis. Both tables were developed by identifying patterns across adaptations described in the scoping review and establishing connections between risk characteristics and PCD elements.

Table 18 'PCD Selection Framework with Example Applications' functions as a selection guide for the 12 PCD adaptations that are discussed in the scoping review. It consists of three elements.

1. Risk Characterisation: Outlines the specific risk characteristics for which each adaptation is most appropriate, including knowledge strength, variability, threshold clarity, and other relevant features for the specific PCD adaptation.
2. Best Use Case: Identifies the primary purpose for which each adaptation is optimally suited.
3. Example Application Areas: Provides concrete examples of contexts where each adaptation might be particularly valuable, helping risk analysts identify which approach might best align with their specific domain.

The second part of the framework, 'Table 19 PCD Element Selection Matrix ', emerged from recognising that risk problems often require combinations of elements from different adaptations rather than selecting a pre-defined approach. This framework was created by deconstructing the twelve PCD adaptations from Chapter 3 into their visual elements (colours, scaling and risk representation). Their suitability conditions were extracted by analysing the limitations and strong points of the adaptation.

Each visual element was rated in relation to the characteristics and purpose of a risk problem. The rating consists of one of three categories: ✓ Recommended ○ Optional/Context-dependent ✗ Not recommended. A visual element is recommended if it contributes to providing decision support under its related goal or characteristic. Consequently, a visual element is not recommended if it does not contribute to decision support. An element is considered Optional / context-dependent if the respective characteristic or purpose does not directly influence the suitability of using (or not using) the visual element.

Neither framework should be applied mechanically. Risk analysts should consider the specific nuances of their context and may need to adapt or combine approaches. In some cases, multiple PCD adaptations might be used complementarily to visualise different aspects of the same risk problem. For example, a bubble diagram could be used for initial risk comparison, followed by a PCD with uncertainty boxes for a more detailed examination of high-priority risks. The modular framework can result in situations where certain visual elements receive conflicting recommendations, depending on the combination of risk characteristics and purposes.

Tabel 19 PCD Selection Framework with Example Applications

Probability Consequence Diagram	Risk Characterisation	Best Use Case	Example Application Areas
Traditional Risk Matrix	Strong knowledge, low variability, positively correlated probability and consequences estimates, clear thresholds	Standardised assessments in well-known domains	Well understood safety risks, routine compliance audits
Matrix with Multiple Consequence Scales	Strong knowledge, low variability, clear thresholds, multiple consequence types	Addressing well-understood risks with multiple impact dimensions	Project risk management, infrastructure development
Matrix with Non-linear Scaling and Grids	Strong knowledge, low variability, clear thresholds	Comparing well-understood risks with wide variations in likelihood and impact	Well understood safety risks with high variability in probability and consequences
Risk Heat Map	Medium to Strong knowledge, low variability, unclear thresholds	Visualising a broad or shifting risk landscape	Strategic planning, dynamic risk tracking, early warning dashboards
Scatter Diagram	Medium to strong knowledge, large number of risks	Comparing and prioritising risk mitigation options	Resource allocation
FN-Curves	Medium to Strong knowledge, Societal risks	Evaluating rare, high-impact fatality risks	Chemical processing, major hazard facilities, public transport safety
Risk Matrix with Confidence Intervals	Strong knowledge, high variability, clear thresholds	Highlighting uncertainties of the consequences estimates	Safety risks with variable consequence estimates
PCD with Uncertainty Boxes	Medium to Strong knowledge, high variability	Highlighting uncertainties of the consequences and probability estimates	Medicine, technical risk assessments
Bubble Diagram	Different degrees of Sok and consequence variability	Visualising risks with varying degrees of SoK	New technologies, early-stage project- and enterprise risk assessment
Risk Plot / Three-Dimensional PCD	Varying degrees of Sok and consequence variability	Visualising risks with varying degrees of SoK	New technologies, early-stage project and enterprise risk assessment
PCD with Strength of Evidence and Deviation Risk Assessment	Weak knowledge, high variability, unclear thresholds	Managing complex risks with multiple uncertainty dimensions	Emerging technologies, large projects with potential for high impact
Risk-Attitude Adaptive Risk Matrix	Weak knowledge, high variability, unclear thresholds	Facilitating decisions with diverse stakeholder values	Public policy, disaster planning, culturally diverse projects, and medicine

Table 20 PCD Element Selection Matrix

→ PCD Elements ↓ Risk Characteristics & Purpose	Colours		Scaling					Risk Representation			
								Confidence Intervals		SoK Indicator	
	Colourd Grid (r/y/g)	Fading Colours	Linear	Logarithmic	Fuzzy Values	Multiple Consequence Scales	ISO Contours	Probability	Consequence	Single	Subdivided
RISK CHARACTERISTICS											
Strong knowledge	○	○	○	○	○	○	○	✗	✗	○	✗
Medium/mixed knowledge	○	○	○	○	○	○	○	✓	✓	✓	✓
Weak knowledge	✗	✓	○	○	○	○	✗	✓	✓	✓	✓
High variability Probabilities	○	○	○	○	○	○	○	✓	○	○	○
High variability Consequences	○	○	○	○	○	○	○	○	✓	○	○
Clear/well-defined Risk Criteria	○	○	○	○	○	○	✓	○	○	○	○
Unclear Risk Criteria	○	○	○	○	○	○	✗	○	○	○	○
Single Consequence Domain	○	○	○	○	○	✗	○	○	○	○	○
Multiple consequence types	○	○	○	○	○	✓	○	○	○	○	○
PURPOSE											
Basic Communication (non-technical)	✓	○	○	○	✓	○	✓	✗	✗	✓	✗
Technical Communication	○	○	○	○	✗	○	○	✓	✓	✓	✓
Regulatory Compliance	○	○	○	○	○	○	✓	○	○	○	○
Resource Allocation	✗	○	○	○	○	○	○	○	○	✓	○
Risk Monitoring/Tracking	✗	✓	○	○	○	○	○	○	○	○	○

Legend: ✓ Recommended ○ Optional/Context-dependent ✗ Not recommended

4.2 Framework Demonstration

This chapter aims to demonstrate the proposed decision framework by applying three fictitious case studies. Whilst not being a valid method for proving the framework's effectiveness, it does provide a structured means to illustrate how the framework can guide the selection of appropriate risk visualisation methods in different contexts. Future research would benefit from empirical validation through field studies, expert interviews, or experiments.

4.2.1 Case Study 1: Risk assessment for warehouse operations.

A large retail company is finalising the construction of a new automated distribution warehouse. Before commencing operations, management has commissioned a comprehensive risk assessment. The warehouse features advanced automated systems, including robotic picking equipment, automated guided vehicles, and conveyor systems. The risk analyst must assess the risks and communicate these effectively to both the operational management team and the company board. Fire safety is separately evaluated as part of the construction of the building.

4.2.1.1 Risk Characterisation

- **Knowledge strength**: Strong – The technology and operational processes are well-established with extensive industry data on similar facilities.
- **Variability**: Low – The operational environment is controlled, and most processes follow standardised procedures.
- **Threshold clarity**: Clear – The company has established risk acceptability thresholds based on regulatory requirements and corporate safety standards.
- **Purpose**: Compliance with safety regulations and communication to multiple stakeholders.
- **Additional factors**: Multiple consequence types (personnel safety, equipment damage, operational disruption, regulatory compliance).

4.2.1.2 Framework Application

Framework 1 suggests a Matrix with Multiple Consequence Scales as the most appropriate adaptation. The strong knowledge base, clear thresholds, and multiple consequence types align with this approach.

The modular framework provides more specific guidance on visual elements. It recommends coloured grid zones due to clear risk criteria and compliance purposes. Linear scaling is suggested given the controlled environment and established processes. Fixed points are recommended due to strong knowledge and low variability. Multiple consequence scales address the multi-dimensional impact types. Lastly, ISO contours show regulatory compliance boundaries.

4.2.1.3 Discussion

Both frameworks offer similar recommendations but suggest different approaches to implementation. Framework 1 provides a quicker solution, especially when organisations have established PCD templates. The risk analyst can swiftly identify that a Matrix with Multiple Consequence Scales fits this scenario and apply an existing format with minimal modification.

Framework 2 offers greater adaptability at the cost of increased complexity. By specifying individual elements (Linear scaling, fixed points, multiple consequence scales, ISO contours), it enables the analyst to construct a PCD tailored to the assessment's requirements.

For this warehouse scenario, either approach can help the risk analyst with selecting an appropriate PCD. Framework 1 delivers efficiency and proven templates, whilst Framework 2 provides the flexibility to optimise the visualisation for the specific combination of strong knowledge, clear criteria, and multi-stakeholder communication needs. The choice between frameworks depends on the analyst's available time, organisational preferences for standardisation versus customisation, and the available tools, knowledge and templates to make either PCD adaptation.

4.2.2 Case Study 2: Environmental Risk Assessment for a Coastal Industrial Development

An energy company is planning a new coastal industrial facility that will include processing and shipping infrastructure. The environmental impact assessment team must evaluate potential ecological risks associated with both routine operations and accidental scenarios. The assessment must consider environmental receptors (marine ecosystems, air quality, groundwater) and account for significant uncertainties regarding impact pathways. The results will inform both regulatory compliance and the communities that could be affected.

4.2.2.1 Risk Characterisation

- **Knowledge strength**: Weak – While general environmental processes are understood, site-specific data is limited, and impact pathways involve complex ecological interactions.
- **Variability**: High – Environmental impacts can vary significantly based on seasonal factors, weather conditions, and ecological responses.
- **Threshold clarity**: Unclear – Regulatory thresholds exist for some parameters but are absent or debated for others.
- **Purpose**: Communication to diverse stakeholders (regulators, community, company management) and supporting risk reduction decisions.
- **Additional factors**: High public interest with diverse risk perceptions among stakeholders.

4.2.2.2 Framework Application

Framework 1 suggests that a Bubble Diagram is the most suitable adaptation. The limited knowledge base, high variability, and diverse stakeholder communication needs align with this approach, which excels at representing uncertainty while remaining comprehensible.

The modular framework offers more specific guidance on visual elements. It suggests fading colours due to limited knowledge and ambiguous criteria. Logarithmic scaling is advised, considering the potentially wide range of consequences. Confidence intervals are recommended due to the high variability in both probability and consequence estimates. Strength of knowledge indicators addresses the uncertainties associated with the plotted risks. ISO contours are not recommended due to unclear regulatory criteria.

4.2.2.3 Discussion

Both frameworks offer recommendations that would lead to similar PCD. Framework 1 provides a quicker solution, as it directly relates to an established format. Framework 2 offers greater adaptability at the cost of increased complexity. By specifying individual elements (fading colours, logarithmic scaling, confidence intervals, and strength of knowledge indicators), it enables the analyst to construct a PCD tailored to the risk problem at hand.

4.2.3 Case Study 3: Cybersecurity Risk Assessment for a Financial Institution

A medium-sized financial institution is conducting its annual cybersecurity risk assessment. The digital threat landscape evolves rapidly, with new attack vectors emerging regularly. The risk analyst must assess the current cybersecurity posture against known threats while also accounting for emerging risks. The assessment must inform both immediate security investments and longer-term security strategy. The analysis involves both well-understood traditional threats and poorly characterised emerging threats.

4.2.3.1 Risk Characterisation

- **Knowledge strength**: Mixed – Strong for established threats with historical data, weak for emerging threats with limited precedent.
- **Variability**: High – Attack frequencies and impact severity can vary widely based on attacker capabilities, motivations, and institutional vulnerabilities.
- **Threshold clarity**: Mixed – Clear thresholds for compliance-related risks, unclear for strategic and emerging risks.
- **Purpose**: Risk monitoring and tracking changes over time, resource allocation for security investments.
- **Additional factors**: Dynamic risk landscape requiring regular reassessment, need to balance technical analysis with executive communication.

4.2.3.2 Framework Application

Framework 1 suggests that a Risk Heat Map is the most suitable adaptation. The dynamic nature of cybersecurity risks, mixed knowledge base, and monitoring purpose align with this approach, which excels at visualising evolving risk landscapes and tracking changes over time.

The modular framework offers more specific guidance on visual elements. It suggests fading colours due to the dynamic risk environment and mixed threshold clarity. Logarithmic scaling is advised given the potentially wide range of cyber attack consequences. Confidence intervals are recommended for high variability in estimates. Strength of knowledge indicators address the mixed evidence quality between established and emerging threats.

4.2.3.3 Discussion

Both frameworks offer recommendations that would lead to a similar visualisation. Framework 1 provides a quicker solution, as it directly points to a heatmap, which is already familiar to many organisations as a PCD. In addition to the elements of a standard heatmap, the adaptive approach advises on SoK indicators, which would be a valuable addition to the heatmap.

4.2.4 Conclusion

The case studies demonstrate that both frameworks provide compatible recommendations. However, there are subtle differences. Framework 1 facilitates quicker selection by drawing upon established PCD adaptations with documented theoretical foundations in the literature. This approach would prove valuable when organisations operate with fixed PCD tools or when a detailed theoretical basis for the PCD is required.

Framework 2 enables optimisation through tailored solutions to specific risk problems. The cybersecurity case exemplifies this distinction: Framework 1 recommended a heat map, whilst Framework 2 additionally prescribed SoK indicators. This addition is valuable considering that cybersecurity risks can be either well-understood or highly uncertain, warranting different risk management strategies.

Whether Framework 2's tailored outputs justify its additional complexity and demands for deeper understanding remains untested. Just as with the various PCDs described in the literature, empirical testing is needed for these frameworks. Real-world case studies can provide insights into the frameworks' practical utility by documenting the experiences of risk analysts and comparing their initial choices with those suggested by the frameworks.

The more modular adaptiveness as used in Framework 2 is a likely future development as risk management increasingly takes place in the digital space, allowing for more adaptive and modular risk visualisations. This evolution towards modular frameworks acknowledges that real-world risk problems often exhibit mixed characteristics requiring adaptive solutions rather than single, predetermined visualisations.

5 Discussion

This thesis has explored the diverse landscape of PCDs, examining their theoretical foundations, practical applications, and potential improvements through both a systematic scoping review and the development of a selection framework for PCD adaptations. The findings reveal a field where scientific consensus on methodological shortcomings coexists with widespread practical reliance on these same criticised tools.

5.1 The Current State of PCD Research

The scoping review demonstrates that, while the literature on PCDs has grown, the main focus is on industry- or problem-specific applications, rather than general, applicable PCD adaptations. This reflects the practical origins of risk matrix development but limits theoretical advancement. Cox's (2008) work continues to provide the primary theoretical foundation, with subsequent research largely building upon his axioms (Bao et al., 2017; Lane & Hrudey, 2023; Levine, 2012; Li et al., 2018).

This pattern suggests that the field has reached a degree of theoretical maturity regarding the limitations of traditional approaches, yet struggles to move toward constructive solutions. Most general studies on PCDs remain conceptual rather than empirical, with Sutherland et al. (2022) and Proto (2023) providing one of the few quantitative analyses of PCD effectiveness in practice. This scarcity of empirical research represents a significant limitation in understanding how different PCD adaptations perform in real-world decision-making contexts.

The twelve PCD adaptations examined in this study show a progression from simple visualisations towards more sophisticated representations that explicitly incorporate uncertainty dimensions. This development reflects contemporary risk definitions that emphasise uncertainty rather than just probability and consequence (Aven, 2013).

This progression does create tension between theoretical sophistication and practical accessibility. Each adaptation exhibits distinct strengths and limitations, making it more or less suitable for specific risk characteristics and audiences. Sophisticated approaches like PCDs with strength of evidence and assumption deviation assessments provide comprehensive uncertainty characterisation but may overwhelm users with visual complexity. Conversely, simpler adaptations, such as traditional risk matrices, lack academic rigour but remain accessible to decision makers across diverse organisational contexts.

5.2 The Science-Practice Gap

One of the observations that motivated this study was the disconnect between industry reliance on risk matrices and academic critiques. Despite consistent scientific agreement on the mathematical limitations and inadequacy of traditional risk matrices for representing uncertainty, risk matrices remain common in risk management. This gap between scientific knowledge and applied practice calls for further exploration, although an in-depth analysis of this observation falls outside the scope of this thesis.

This apparent contradiction can partly be reconciled by understanding that PCDs, at their core, function as a graphical representation and communication tool rather than a definitive analytical method. Whilst analytical precision is desirable, the actual effectiveness of a PCD lies in its ability to provide decision support. Therefore, evaluating PCDs solely on their mathematical rigour overlooks their primary role in conveying risk information to decision-makers.

This functional explanation, however, is insufficient to account for the consistent use of traditional risk matrices. New PCD adaptations address many of the problems found with the traditional risk matrix. Yet, the traditional risk matrix remains a common tool. The appeal of traditional risk matrices could possibly be explained through organisational symbolism. As Jordan et al. (2018) observed, risk matrices can function as collective symbols that provide a common language and shared visual representation of risk. In ambiguous and chaotic environments, symbols help resolve confusion and provide direction. The act of populating and reviewing a risk matrix can become a ritual that reinforces a sense of control and due diligence, even when its analytical output is imperfect.

5.3 Framework Contributions and Limitations

The framework presented in this thesis addresses a gap identified in the literature. The absence of systematic guidance for selecting appropriate PCD adaptations based on risk characteristics and requirements. Without guidance, practitioners may choose visualisation methods based on organisational habits, software availability, or personal preference instead of suitability, which could result in inappropriate visualisations that do not provide accurate decision support.

The framework's primary contribution lies in providing guidance that matches PCD capabilities to specific risk problem characteristics and risk management goals. By recognising that PCDs serve as risk management tools, the framework extends beyond purely technical limitations to encompass the broader dimensions of risk problem characteristics and the intended purpose of the visualisation.

Two frameworks were developed to address this gap in the literature. Framework 1 'PCD Selection Framework with Example Applications' directly matches established PCD types to specific risk characteristics and contexts, facilitating quick selection through proven approaches with documented theoretical foundations. Framework 2 'PCD Element Selection Matrix' provides modular element selection, enabling analysts to construct visualisations by combining individual visual elements based on the risk characteristics and the intended purpose of the visualisation.

Rather than advocating for the universal adoption of the most sophisticated approach, the frameworks recognise that simpler tools may be more suitable than complex alternatives. However, several limitations must be acknowledged. The framework relies on judgements regarding risk characteristics that may vary among risk analysts. Real-world risk problems often exhibit mixed characteristics that might benefit from hybrid approaches instead of selecting a single method. The framework's binary approach to risk characteristics (strong/weak knowledge, high/low variability) may oversimplify the continuous nature of these dimensions in practice. Additionally, Framework 2 can yield contradictory output on which element to include. For instance, when weak knowledge is a characteristic of the risk problem, but risk compliance or basic (non-technical) risk communication is the intended purpose. Future research and refinements are necessary to address these limitations.

5.4 Methodological Reflections

The methodology of this thesis consisted of literature research through a scoping review, combined with conceptual risk science. This method has provided a solid theoretical foundation for developing a selection framework for PCD adaptations. There are, however, several limitations that must be considered with this approach.

The scoping review process was affected by a scope refinement that occurred after the initial search strategy was implemented. Initially, the search focused on "risk matrices" and related terms. However, it became clear during the review process that this terminology was too restrictive to capture the full breadth of risk visualisation tools relevant to the research questions. Therefore, the scope was expanded to encompass the broader concept of "Probability-Consequence Diagrams" (PCDs), which includes visualisation approaches beyond traditional matrix formats. This could potentially mean that some PCD adaptations using alternative terminology were not identified in the review, despite being relevant to the expanded research scope. However, PCDs are typically discussed in relation to risk matrices and related terms throughout the literature, as these terms remain the predominant terminology in practice. The chance of a relevant publication on PCDs not being included is therefore small because any relevant study would likely mention one or more of the related terms from the original search query.

Lastly, the framework development process relied heavily on the researcher's interpretation of the literature. Greater involvement of practitioner perspectives through interviews, surveys, or participatory design approaches could enhance the framework's practical relevance and validity. The absence of empirical validation also represents a limitation that future research should address.

5.5 Future Research Directions

Several directions for future research emerge from this study. Most critically, empirical research on the effectiveness of PCD is lacking. The real (in)-effectiveness of PCDs is, by and large, unknown. Studies examining decision quality using different PCD adaptations would provide valuable insights for refining both PCD adaptations themselves and selection frameworks.

The development of more adaptive and modular PCD approaches represents a promising direction as risk management increasingly moves into digital environments. Such approaches could allow real-time adjustment of visualisation elements based on user characteristics, risk contexts, or stakeholder feedback, potentially bridging the gap between theoretical sophistication and practical accessibility. Therefore, research and development of these adaptive systems is essential to realise their potential for enhancing decision support.

Another relevant direction for future research is the study of PCDs in organisations, addressing the question of why particular PCD adaptations are used despite (in some cases) not providing accurate decision support. Such research could examine the organisational functions these tools serve, whether as symbols of compliance, tools for communication, or instruments of risk analysis. Such studies could reveal how the symbolic significance of these tools within organisational contexts may be as influential as their technical capabilities in determining their continued use and evolution.

Despite the limitations identified, this thesis contributes to the field by providing a systematic mapping of PCD adaptations and offering structured guidance for their selection. It establishes a foundation for future empirical research and highlights the complex interplay between theoretical advancement and practical utility in risk visualisation. The framework, whilst requiring further validation and refinement, offers a starting point for more systematic matching of PCD adaptations to the contexts where they can provide optimal value for risk communication and decision-making.

6 Conclusion

This thesis has investigated the diverse landscape of PCD designs, their theoretical foundations, and practical applications, with the aim of developing a framework to assist risk assessors in selecting the most appropriate PCD adaptation based on risk characteristics and the intended purpose of the visualisation.

To address the main research question, the research was divided into two primary investigations, each with its own research question. This conclusion will first answer these sub-questions. After this, the main research question will be answered.

The first sub-question was: *What are the different types of risk matrix designs, their theoretical foundations, practical applications, strong points and shortcomings?* This question was answered through conducting a scoping review. The scoping review identified twelve general applicable PCD adaptations: *1) Traditional risk matrix, 2) Risk matrix with multiple consequence scales, 3) Risk matrix with non-linear scaling and grids, 4) Heat map, 5) Scatter diagram, 6) FN-curves, 7) Risk matrix with confidence intervals, 8) PCD with uncertainty boxes, 9) Bubble diagram, 10) Risk plot/three-dimensional PCD, 11) PCD with strength of evidence and assumption deviation risk assessment, and 12) Risk attitude adaptive risk matrix.*

The PCD adaptations are grounded in mathematical principles, with most building upon the risk concept of probability multiplied by consequence (P×C). Cox's (2008) work remains the most influential in the field, providing the primary framework for evaluating PCD effectiveness through his axioms of weak consistency, betweenness, and consistent colouring, with subsequent research largely building upon these axioms to assess new adaptations. Newer approaches incorporate uncertainty-based risk perspectives. Demonstrating a theoretical progression from basic matrices to sophisticated multi-dimensional representations that explicitly address uncertainty.

The literature reveals that PCDs are applied across a wide range of industries and contexts, with many studies focusing on specific PCD adaptations tailored to particular problems and sectors. This demonstrates the broad utility and adaptability of risk visualisation approaches across diverse domains. However, for the twelve generally applicable PCD adaptations identified in this review, specific applications did not become apparent. These general adaptations represent formats that can be applied across different settings rather than being tied to specific industries or problem types.

Each PCD adaptation exhibits distinct strengths and weaknesses, mainly reflecting trade-offs between simplicity and academic rigour. Some PCDs successfully address mathematical limitations identified in traditional approaches, but often at the cost of increased complexity. There is no perfect PCD adaptation, as all represent necessary simplifications of reality. However, by systematically acknowledging the strengths and weaknesses of each adaptation, more informed selection decisions can be made to improve decision support.

The second sub-research question was: *Can a framework be developed to assist risk assessors in selecting the most suitable risk matrix adaptation based on risk characteristics, and if so, how would such a framework be structured?*

Yes, a framework can be developed to assist risk assessors in PCD selection. Two complementary frameworks were developed based on the analysis of the twelve PCD adaptations identified in the scoping review.

Framework 1 (PCD Selection Framework with Example Applications) provides direct matching of established PCD types to specific risk characteristics and contexts, facilitating quick selection through proven approaches. Framework 2 (PCD Element Selection Matrix) offers a modular approach, enabling analysts to construct tailored visualisations by combining visual elements based on risk characteristics and intended purposes.

Both frameworks are structured around the risk characteristics and purpose of the visualisation. The frameworks were demonstrated through three fictitious case studies, which showed compatible recommendations while offering different implementation approaches. Framework 1 emphasises efficiency and proven templates, Framework 2 enables a modular approach that allows for the construction of tailored PCD adaptations.

The overarching question that guided the research was: *"What are the different types of Probability Consequence Diagram (PCD) designs, their theoretical foundations, and practical applications, and can a structured framework be developed to assist risk assessors in selecting the most appropriate PCD adaptation based on risk characteristics?"*

Combining the answers to the sub-questions addresses the overarching research question. The scoping review successfully mapped twelve different types of generally applicable PCD designs, revealing their theoretical foundations rooted in P×C definitions of risk, as well as more contemporary definitions that incorporate an element of uncertainty. Each adaptation exhibits distinct strengths and limitations, with a clear progression from simple, accessible tools to sophisticated, uncertainty-conscious visualisations.

Building upon this scoping review, two frameworks were developed to assist risk assessors in selecting appropriate PCD adaptations. The frameworks address a gap in the literature by providing structured guidance that matches PCD capabilities to specific risk characteristics and risk management purposes.

The research demonstrates that diverse PCD designs exist with well-documented foundations and applications, and that frameworks can be developed to guide their selection. These frameworks represent the first systematic approach to PCD selection, moving beyond generic criticism to provide practical guidance for the application of these widely used risk visualisations.

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Lane, K., & Hrudey, S. E. (2023). A critical review of risk matrices used in water safety planning: improving risk matrix construction. *Journal of Water and Health*, *21*(12), 1795-1811. https://doi.org/10.2166/wh.2023.129

Levine, E. S. (2012). Improving risk matrices: the advantages of logarithmically scaled axes. *Journal of risk research*, *15*(2), 209-222. https://doi.org/10.1080/13669877.2011.634514

Li, J., Bao, C., & Wu, D. (2018). How to Design Rating Schemes of Risk Matrices: A Sequential Updating Approach. *Risk Analysis*, *38*(1), 99-117. https://doi.org/10.1111/risa.12810

McMeekin, N., Wu, O., Germeni, E., & Briggs, A. (2020). How methodological frameworks are being developed: evidence from a scoping review. *BMC Medical Research Methodology*, *20*(1), 173. https://doi.org/10.1186/s12874-020-01061-4

Morgan, M. G., Fischhoff, B., Bostrom, A., & Atman, C. J. (2002). *Risk communication: A mental models approach.* Cambridge University Press.

Peace, C. (2017). The risk matrix: Uncertain results? *Policy and Practice in Health and Safety*, *15*(2), 131-144. https://doi.org/10.1080/14773996.2017.1348571

Pollock, D., Evans, C., Menghao Jia, R., Alexander, L., Pieper, D., Brandão de Moraes, É., Peters, M. D. J., Tricco, A. C., Khalil, H., Godfrey, C. M., Saran, A., Campbell, F., & Munn, Z. (2024). "How-to": scoping review? *Journal of Clinical Epidemiology*, *176*, 111572. https://doi.org/10.1016/j.jclinepi.2024.111572

Rayyan. (2025). *Intelligent Systematic Review*. In Rayyan Systems. https://www.rayyan.ai/

Renn, O. (2008). *Risk governance: Coping with uncertainty in a complex world*. Earthscan. ISBN: 978-1844072927

Schmidt, M. S. (2016). Making sense of risk tolerance criteria. *Journal of loss prevention in the process industries*, *41*, 344-354. https://doi.org/10.1016/j.jlp.2015.12.005

Slovic, P. (1987). Perception of Risk. *Science*, *236*(4799), 280-285. http://www.jstor.org/stable/1698637

Tiusanen, R., Rollenhagen, C., Ove Hansson, S., Moller, N., & Holmberg, J. E. (2017). Qualitative Risk Analysis. In (pp. 463-492). Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/9781119443070.ch21

Tzelgov, J., Meyer, J., & Henik, A. (1992). Automatic and intentional processing of numerical information. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(1), 166-179. https://doi.org/10.1037/0278-7393.18.1.166

Appendix A1 Initial Search Results

Oria

Source	Category	Relevance	Comment
Risk Matrix Helps Staff Make Decisions, Take Responsibility. (2017). Healthcare Risk Management, 39(3).	IA - R&DM	+-	
Acebes, F., Gonzalez-Varona, J. M., Lopez-Paredes, A., & Pajares, J. (2024). Beyond probability-impact matrices in project risk management: A quantitative methodology for risk prioritisation. Humanities & social sciences communications, 11(1), 670-613. https://doi.org/10.1057/s41599-024-03180-5	R&DM	+-	*novel approach for prioritising project risks*
Ahmed, Q., I. Khan, F., & A. Raza, S. (2014). A risk-based availability estimation using Markov method. The International journal of quality & reliability management, 31(2), 106-128. https://doi.org/10.1108/IJQRM-04-2012-0056	IA - R&DM	+-	*Risk-based availability Markov model (RBAMM).*
Alekseev, A., Mingaleva, Z., Alekseeva, I., Lobova, E., Oksman, A., & Mitrofanov, A. (2023). Developing a Numerical Method of Risk Management Taking into Account the Decision-Maker's Subjective Attitude Towards Multifactorial Risks. Computation, 11(7), 132. https://doi.org/10.3390/computation11070132	IA - R&DM	+-	*Managing multifactorial risks using mathematical methods for determining the optimal risk management trajectories separately for each factor.*
American Institute of Chemical Engineers. Center for Chemical Process, S. (2020). Guide for making acute risk decisions. CCPS : Wiley.	IA - R&DM	+	Book
Arbatli, E. C., & Johansen, R. M. (2017). A Heatmap for Monitoring Systemic Risk in Norway. In: Norges Bank.	IA	+-	
Aven, T. (2008). Discussion. In (pp. 143-166). Chichester, UK: John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470694435.ch13	SF	+	Book
Aven, T. (2017). Improving risk characterisations in practical situations by highlighting knowledge aspects, with applications to risk matrices. Reliability engineering & system safety, 167, 42-48. https://doi.org/10.1016/j.ress.2017.05.006	SF	++	*Practical methods are reviewed and discussed, in particular extended risk matrices*
Aven, T. (2018). The meaning of black swans. In (Vol. 1, pp. 33-48). Routledge. https://doi.org/10.4324/9781315557540-4	SF	-	Not specific to Risk Matrices
Aven, T. (2020). Fundamentals about the risk concept and how to describe risk. In (pp. 57-86). United Kingdom: Routledge. https://doi.org/10.4324/9780429029189-4	SF	-	Not specific to Risk Matrices
Aven, T., & Thekdi, S. (2022). Measuring and describing risk. In (pp. 24-58). Routledge. https://doi.org/10.4324/9781003156864-4	SF	+	Extensive scientific background on measuring risk
Ball, D. J., & Watt, J. (2013). Further Thoughts on the Utility of Risk Matrices. Risk Analysis, 33(11), 2068-2078. https://doi.org/10.1111/risa.12057	SF-R&DM	+	*''This article further examines the reliability and utility of risk matrices for ranking hazards, specifically in the context of public leisure activities including travel''.*
Bao, C., Li, J., & Wu, D. (2018). A fuzzy mapping framework for risk aggregation based on risk matrices. Journal of risk research, 21(5), 539-561. https://doi.org/10.1080/13669877.2016.1223161	SF	+-	Focus on the aggregation if risk in matrices
Bao, C., Wu, D., Wan, J., Li, J., & Chen, J. (2017). Comparison of Different Methods to Design Risk Matrices from The Perspective of Applicability. Procedia computer science, 122, 455-462. https://doi.org/10.1016/j.procs.2017.11.393	IA	+	Comparison of Risk Matrices
Baybutt, P. (2014). The use of risk matrices and risk graphs for SIL determination. Proc. Safety Prog, 33(2), 179-182. https://doi.org/10.1002/prs.11627	IA	+-	Critique on safety risk matrices
Baybutt, P. (2018). Guidelines for designing risk matrices. Process safety progress, 37(1), 49-55. https://doi.org/10.1002/prs.11905	IA	+-	Practical application of risk matrices

Baz, J., Martinez, M., Diaz-Vazquez, S., & Montes, S. (2024). On the Construction of Admissible Orders for Tuples and Its Application to Imprecise Risk Matrices. International journal of computational intelligence systems, 17(1), 1-14. https://doi.org/10.1007/s44196-024-00575-9	SF	+	Focus on the theoretical foundations of ranking risk in matrices.
Behie, S., Lu, Y., Buxton, G., Slezak, M., & Schambach, H. (2016). Critical Mitigation Element methodology: An approach to achieving consistent risk evaluation results. Journal of loss prevention in the process industries, 44, 661-670. https://doi.org/10.1016/j.jlp.2016.08.011	IA	+-	Focus on risk matrices in the Oil and gas industry
Berghahn Crija, U., Olivier-Maget, N., Bourgeois, F., Gabas, N., & Iddir, O. (2019). Interfacing the Probabilistic Bowtie Analysis with the Regulatory Risk Matrix. Chemical engineering transactions, 77. https://doi.org/10.3303/CET1977154	IA	+-	Focus on combining probabilistic bowties with regulator risk matrices
Bier, V. (2020). The Role of Decision Analysis in Risk Analysis: A Retrospective. Risk Anal, 40, 2207-2217. https://doi.org/10.1111/risa.13583	R&DM	+	Literature review on the combination of risk analysis and decision making.
Bognár, F., & Hegedűs, C. (2022). Analysis and Consequences on Some Aggregation Functions of PRISM (Partial Risk Map) Risk Assessment Method. Mathematics (Basel), 10(5), 676. https://doi.org/10.3390/math10050676	SF	-	The PRISM method emphasizes the identification and ranking of hidden risks and uses advanced multi-criteria decision-making (MCDM) techniques.
Boussabaine, A., Kirkham, R., Boussabaine, H. A., & Kirkham, R. J. (2003). Whole Life Risk Analysis Techniques. In (pp. 56-83). United Kingdom: John Wiley & Sons, Incorporated. https://doi.org/10.1002/9780470759172.ch5			No access
Boussabaine, H. A. (2004). Whole life-cycle costing : risk and risk responses. Blackwell Pub.	IA		No access
Bryce, C., Ashby, S., & Ring, P. (2024). Reconciling risk as threat and opportunity: The social construction of risk in boardrooms. Risk Anal, 44(8), 1959-1976. https://doi.org/10.1111/risa.14275	R&DM	-	Risk matrix not the main focus
Can, G. F., & Toktas, P. (2018). A novel fuzzy risk matrix based risk assessment approach. Kybernetes, 47(9), 1721-1751. https://doi.org/10.1108/K-12-2017-0497	IA	-	One specific application (warehouse management)
Carbone, T. A., & Tippett, D. D. (2004). Project Risk Management Using the Project Risk FMEA. Engineering management journal, 16(4), 28-35. https://doi.org/10.1080/10429247.2004.11415263	IA	-	Not about risk matrices
Center for Chemical Process, S., & Ccps. (2017). Other Asset Management Tools. In (pp. 1-1). United States: Center for Chemical Process Safety/AIChE (CCPS). https://doi.org/10.1002/9781119364276.ch15	IA	-	No in-depth analysis on risk matrixes
Center for Chemical Process Safety, A., & Ccps. (2020). Using LOPA and Risk Matrices in Risk Decisions. In (pp. 1-1). United States: Center for Chemical Process Safety/AIChE (CCPS). https://doi.org/10.1002/9781119669043.ch9	IA		Duplicate; see above
Cox, A. L., Jr. (2008). What's Wrong with Risk Matrices. Risk Anal, 28(2), 497-512. https://doi.org/10.1111/j.1539-6924.2008.01030.x	SF	++	Highly relevant
Cox, L. A., Jr. (2009). What's Wrong with Hazard-Ranking Systems? An Expository Note. Risk Anal, 29(7), 940-948. https://doi.org/10.1111/j.1539-6924.2009.01209.x	SF	+	More specific to hazard ranking than risk visualisations
Cutajar, S., Smigoc, H., & O'Hagan, A. (2017). Actuarial Risk Matrices: The Nearest Positive Semidefinite Matrix Problem. North American actuarial journal, 21(4), 552-564. https://doi.org/10.1080/10920277.2017.1317273	SF	-	Specific risk matrix adaptation for actuarial risk
Diekmann, F. J. (2012). CFOs Urged To Take Look At Risk Matrix Model. Credit Union Journal, 16(24), 12.			No Access
Dominique, L., Xiao, Q., & Srinivas, R. G. (2021). Chapter 5 - Exploratory analyses of safety data. In (pp. 135-177). Elsevier Inc. https://doi.org/10.1016/B978-0-12-816818-9.00015-9	SF	-	Paper focusses on general statistical analysis and graphs
Duijm, N. J. (2015). Recommendations on the use and design of risk matrices. Safety science, 76, 21-31. https://doi.org/10.1016/j.ssci.2015.02.014	SF	++	Highly relevant
Elmontsri, M. (2014). Review of the Strengths and Weaknesses of Risk Matrices. Journal of risk analysis and crisis response, 4(1), 49. https://doi.org/10.2991/jrarc.2014.4.1.6	IA – SF	+	Discussion of risk matrix using the applications in Health.

Etnel, J. R. G., de Groot, J. M., El Jabri, M., Mesch, A., Nobel, N. A., Bogers, A. J. J. C., & Takkenberg, J. J. M. (2020). Do risk visualizations improve the understanding of numerical risks? A randomized, investigator-blinded general population survey. Int J Med Inform, 135, 104005-104005. https://doi.org/10.1016/j.ijmedinf.2019.104005	R&DM	+-	Some relevance related to the understanding of risk and visualisations.
Franks, A. P., & Maddison, T. (2006). A Simplified Method for the Estimation of Individual Risk. Process safety and environmental protection, 84(2), 101-108. https://doi.org/10.1205/psep.04287	IA – R&DM	+-	Specific risk matrix adaptation for assessing personal risk
Goerlandt, F., & Reniers, G. (2016). On the assessment of uncertainty in risk diagrams. Safety science, 84, 67-77. https://doi.org/10.1016/j.ssci.2015.12.001	SF	++	Highly relevant paper on the incorporation of uncertainties in Risk matrices
Gong, Y., Zheng, J.-Y., Xu, X., Peng, H., Qu, Y.-H., & Yang, L.-L. (2022). Discussion on the Application of Risk Matrix Method in Regional Nuclear and Radiation Risk Assessment.	IA	-	To specific application of risk matrix
Goulding, L. (2023). Spotlights: A Historical Risk Matrix Paper, VR Lab Safety Training, and a Systematic Approach for Identifying Unknown Assumptions. ACS Chemical Health & Safety., 30(6), 341-342. https://doi.org/10.1021/acs.chas.3c00098	IA	-	No additional insight provided
Gul, M., & Ak, M. F. (2018). A comparative outline for quantifying risk ratings in occupational health and safety risk assessment. Journal of cleaner production, 196, 653-664. https://doi.org/10.1016/j.jclepro.2018.06.106	IA	+-	Relevant insights on the validity of fuzzy sets in safety management
Haimes, Y. Y. (2004). Risk Filtering, Ranking, and Management. In (pp. 276-295). Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/0471723908.ch7	IA	+-	Mostly general information on the use of risk matrices
Hans, S., Tijs, K., & Ulrich, H. (2019). Semiquantitative Risk Analysis.An EPSC Working Group. Chemical engineering transactions, 77. https://doi.org/10.3303/CET1977007	IA	-	To specific application of risk matrix
Häring, I. (2015). Risk Analysis and Management: Engineering Resilience. Springer Singapore : Imprint: Springer.	IA	+-	Some relevance on the usage of risk matrices
Häring, I. (2016). Risk Computation and Visualization. In (pp. 251-270). Singapore: Springer Singapore Pte. Limited. https://doi.org/10.1007/978-981-10-0015-7_14			Duplicate, see above
Haugen, S., Rausand, M., Rausand, M., & Haugen, S. (2020). Measuring Risk. In (pp. 1-1). United States: John Wiley & Sons. https://doi.org/10.1002/9781119377351.ch6	IA	-	Only general information on the use of risk matrices
Høj, N. P., Kroon, I. B., Nielsen, J. S., & Schubert, M. (2025). System risk modelling and decision-making – Reflections and common pitfalls. Structural safety, 113, 102469. https://doi.org/10.1016/j.strusafe.2024.102469	SF	+	Relation between FN-curves and risk matrices
Hong, Y., Pasman, H. J., Quddus, N., & Mannan, M. S. (2020). Supporting risk management decision making by converting linguistic graded qualitative risk matrices through interval type-2 fuzzy sets. Process safety and environmental protection, 134, 308-322. https://doi.org/10.1016/j.psep.2019.12.001	SF	+	On improving the understanding of fuzzy sets
Hubbard, D. W. (2020). A Summary of the Current State of Risk Management. In (pp. 21-34). Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/9781119521914.ch2	IA	+	Some relevant insights in how risk matrices are used by organisations
Hubbard, D. W. (2020). Worse Than Useless. In (pp. 163-192). Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/9781119521914.ch8	IA		Same book as above
Institute of, P. (2022). Challenges in Risk Analysis for Science and Engineering : Development of a Common Language. IOP Publishing.	IA	+-	Specific Risk matrix applications in practice
Ivascu, L., Artene, A. E., Ren, J., & Ren, J. (2021). Risk Assessment: Indicators and Organizational Models. In (Vol. 1, pp. 1-20). Switzerland: Springer International Publishing AG. https://doi.org/10.1007/978-3-030-78152-1_1	SF	-	No in depth analysis of risk matrices
Jenkins, R. V. (2021). Using Consequence-Based Assessment Techniques to Improve Standard Risk Matrix Results.			No Access
Jensen, R. C., & Hansen, H. (2020). Selecting Appropriate Words for Naming the Rows and Columns of Risk Assessment Matrices. International journal of environmental research and public health, 17(15), 5521. https://doi.org/10.3390/ijerph17155521	SF – R&DM	+	Insights in determining the names for the rows and columns of risk matrices

Jianxing, Y., Haicheng, C., Shibo, W., & Haizhao, F. (2021). A Novel Risk Matrix Approach Based on Cloud Model for Risk Assessment Under Uncertainty. IEEE access, 9, 27884-27896. https://doi.org/10.1109/ACCESS.2021.3058392	IA	-	To specific application of risk matrix
Jordan, S., Mitterhofer, H., & Jørgensen, L. (2018). The interdiscursive appeal of risk matrices: Collective symbols, flexibility normalism and the interplay of 'risk' and 'uncertainty'. Accounting, organizations and society, 67, 34-55. https://doi.org/10.1016/j.aos.2016.04.003	SF – R&DM	++	Highly relevant paper on a broad range of risk matrices and there foundations and applications
Jørgensen, L., Lindøe, P. H., Lindøe, P. H., Juhl, K., Olsen, O. E., & Engen, O. A. (2020). Standardizations and risk mapping: Strengths and weaknesses. In (pp. 181-198). Routledge. https://doi.org/10.4324/9780429290817-14	SF – R&MD-IA	+	Empirical study on the use of risk matrices in the Oil and Gas sector and some SF discussions
Lane, K., & Hrudey, S. E. (2023). A critical review of risk matrices used in water safety planning: improving risk matrix construction. J Water Health, 21(12), 1795-1811. https://doi.org/10.2166/wh.2023.129	R&MD-IA	+	Comparison of different types of risk matrices in water management.
Levine, E. S. (2012). Improving risk matrices: the advantages of logarithmically scaled axes. Journal of risk research, 15(2), 209-222. https://doi.org/10.1080/13669877.2011.634514	SF	+	Insights on making a risk matrix
Li, J., Bao, C., & Wu, D. (2018). How to Design Rating Schemes of Risk Matrices: A Sequential Updating Approach. Risk Anal, 38(1), 99-117. https://doi.org/10.1111/risa.12810	SF	+	Design of risk matrices (Determining the levels)
Li, Z. P., Yee, Q. M. G., Tan, P. S., & Lee, S. G. (2013). An extended risk matrix approach for supply chain risk assessment.			No access
Lin, C. (2018). A literature review of risk matrices applied for risk assessment in geotechnical engineering. In Deliverable D5.1. Work Package 5 – Risk assessment and management: NGI - Norges Geotekniske Institutt.	IA	-	Types of risk matrices used for tunnels. (To narrow scope)
Lutchman, C., Maharaj, R., & Ghanem, W. (2012). The Challenges of Risk Management. In (pp. 157-168). United Kingdom: CRC Press. https://doi.org/10.1201/b11720-14	IA	-	Only a simplified risk matrix is discussed
MacKenzie, C. A. (2014). Summarizing Risk Using Risk Measures and Risk Indices. Risk Analysis, 34(12), 2143-2162. https://doi.org/10.1111/risa.12220	SF	+-	Comparison and communication of societal risks
Markowski, A. S., & Mannan, M. S. (2008). Fuzzy risk matrix. J Hazard Mater, 159(1), 152-157. https://doi.org/10.1016/j.jhazmat.2008.03.055	SF	+-	Relation between fuzzy and non fuzzy sets
Mauro, E. (2019). Best Practice and Common Practice in Risk Assessment.			No Acces
Mitterhofer, H., Jordan, S., Zinn, J. O., Burgess, A., & Alemanno, A. (2016). Imagining risk: The visual dimension in risk analysis. In (pp. 318-334). Routledge. https://doi.org/10.4324/9781315776835-37	IA	+	The background of different types of risk visualisations explained
Mohammadiyan, M., Ahmadi, O., Yaseri, M., & Karimi, A. (2024). Application of Three-Dimensional Risk Matrix Approach for Occupational Injury Risk assessment in an Automotive Factory. Bihdāsht va īmanī-i kār. https://doi.org/10.18502/jhsw.v14i2.17141	IA	-	To narrow scope
Oboni, F., & H. Oboni, C. (2021). B.7.2 Newly Recognized Risk Matrices Deficiencies. In. Switzerland: Springer International Publishing AG.	SF - IA	+	Insights on risk matrix limitations written in popular language
Oboni, F., & H. Oboni, C. (2021). B.7.3 Can We Solve the Deficiencies of Risk Matrices? In. Switzerland: Springer International Publishing AG.			Duplicate, see above
Pan, J.-y., & Wang, F. (2009). Analysis and Assessment of Collaboration and Innovation Risks Based on Risk Matrix.			No access
Peacock, D. C. P. (2025). The certainty matrix for fault data and interpretations. Geothermics, 125, 103197. https://doi.org/10.1016/j.geothermics.2024.103197		-	Not about risk management
Peeters, W., & Peng, Z. (2015). An Approach Towards Global Standardization of the Risk Matrix. Journal of space safety engineering, 2(1), 31-38. https://doi.org/10.1016/S2468-8967(16)30037-4	SF- IA	+	proposes a standardised framework to improve consistency
Pei, M., Liu, S., Wen, H., & Wang, W. (2023). A developed gained and lost dominance score method for risk prioritization in FMEA with Fermatean fuzzy information. Journal of intelligent & fuzzy systems, 44(6), 8905-8923. https://doi.org/10.3233/JIFS-222692	SF	-	Not specific to risk matrices

Plotnikov, N. I., Mendes de Seixas, A. C., Gomes de Oliveira, G., Saotome, O., Iano, Y., Kemper, G., Saotome, O., Gomes de Oliveira, G., Mendes de Seixas, A. C., Iano, Y., & Kemper, G. (2021). Soft Computing Method in Events Risks Matrices. In (Vol. 233, pp. 578-588). Switzerland: Springer International Publishing AG. https://doi.org/10.1007/978-3-030-75680-2_64	SF	+	Proposes the use of "soft computing" techniques, incorporating various measures
Prasad, S. B. (2011). A matrixed assessment: auditors can use a risk matrix to facilitate a holistic review of their organization's ERM program. The Internal Auditor, 68(6), 63.	IA	-	No in-depth discussion of risk matrices
Proto, R., Recchia, G., Dryhurst, S., & Freeman, A. L. J. (2023). Do colored cells in risk matrices affect decision-making and risk perception? Insights from randomized controlled studies. Risk Anal, 43(10), 2114-2128. https://doi.org/10.1111/risa.14091	R&DM	++	One of the few quantitative studies on the effectiveness of risk matrices in decision-making
Pursiainen, C. (2018). Risk assessment. In (pp. 9-38). United Kingdom: Routledge. https://doi.org/10.4324/9781315629179-2	SF – R&DM	+-	Some relevance but no in-depth analysis of risk matrices
Qazi, A., & Dikmen, I. (2021). From Risk Matrices to Risk Networks in Construction Projects. IEEE transactions on engineering management, 68(5), 1449-1460. https://doi.org/10.1109/TEM.2019.2907787			No access
Qazi, A., Dikmen, I., & Birgonul, M. T. (2020). Prioritization of interdependent uncertainties in projects. International journal of managing projects in business, 13(5), 913-935. https://doi.org/10.1108/IJMPB-10-2019-0253			No access
Ratnayake, R. M. C., & Antosz, K. (2017). Development of a Risk Matrix and Extending the Risk-based Maintenance Analysis with Fuzzy Logic. Procedia engineering, 182, 602-610. https://doi.org/10.1016/j.proeng.2017.03.163	IA	-	Focus on maintenance, not risk
Rausand, M., & Rausand, M. (2011). How to Measure and Evaluate Risk. In (pp. 77-116). Hoboken, New Jersey: John Wiley & Sons, Inc. https://doi.org/10.1002/9781118281116.ch4	SF – R&DM	++	Thorough discussion of the SF with examples of different matrices
Reniers, G. L. L., & Sörensen, K. (2013). An Approach for Optimal Allocation of Safety Resources: Using the Knapsack Problem to Take Aggregated Cost-Efficient Preventive Measures. Risk Analysis, 33(11), 2056-2067. https://doi.org/10.1111/risa.12036	R&DM	+	Analysis on the analysis of costs risk reducing measures in matrices.
Russell Vastveit, K. (2011). The use of national risk assessments in the Netherlands and the UK. In: University of Stavanger, Norway.	R&DM	-	No in-depth analysis of risk matrices
Sadiq, N. (2019). Appendix D: A 6x6 risk matrix for severity and likelihood. In. United Kingdom: IT Governance Ltd.	IA	-	No in-depth analysis of risk matrices
Schmidt, M. S. (2016). Making sense of risk tolerance criteria. Journal of loss prevention in the process industries, 41, 344-354. https://doi.org/10.1016/j.jlp.2015.12.005	SF – R&DM	+	Insight on visualising tolerance levels in risk matrices
Sivitski, A., & Põodra, P. (2021). Risk Assessment and Calibration of Risk Matrices Aspects. IOP Conf. Ser.: Mater. Sci. Eng, 1140(1), 12040. https://doi.org/10.1088/1757-899X/1140/1/012040	SF – R&DM	+-	Insights on calibrating a risk matrix
Slavin, D., Troy Tucker, W., Ferson, S., Tucker, W. T., Ferson, S., & Finkel, A. M. (2008). A Frequency/Consequence-based Technique for Visualizing and Communicating Uncertainty and Perception of Risk. Ann N Y Acad Sci, 1128(1), 63-77. https://doi.org/10.1196/annals.1399.008	SF	+	Focus on visualising uncertainties, particularly in a software application
Sommestad, T., Karlzén, H., Nilsson, P., & Hallberg, J. (2016). An empirical test of the perceived relationship between risk and the constituents severity and probability. Information and computer security, 24(2), 194-204. https://doi.org/10.1108/ICS-01-2016-0004	R&DM	-	Study on the concept of C*P for security risks
Stephens, S. H., & DeLorme, D. E. (2019). A Framework for User Agency during Development of Interactive Risk Visualization Tools. Technical communication quarterly, 28(4), 391-406. https://doi.org/10.1080/10572252.2019.1618498	Other	-	Broader study on the development of visualisations
Sutherland, H., Recchia, G., Dryhurst, S., & Freeman, A. L. J. (2022). How People Understand Risk Matrices, and How Matrix Design Can Improve their Use: Findings from Randomized Controlled Studies. Risk Anal, 42(5), 1023-1041. https://doi.org/10.1111/risa.13822	R&DM	+	Suggestion of the use of different shaped fields to increase logarithmic awareness in matrices
Tian, D., Chen, J., & Wu, X. (2022). A two stage risk assessment model based on interval-valued fuzzy numbers and risk attitudes. Engineering applications of artificial intelligence, 114, 105086. https://doi.org/10.1016/j.engappai.2022.105086	SF – IA	+-	multi-expert and multi-criterion information fusion (MEMC-IF) model and defuzzyfication methods proposed

Tian, D., Min, C., Li, L., & Gao, J. (2020). A MCMEIF-LT model for risk assessment based on linguistic terms and risk attitudes. Applied intelligence (Dordrecht, Netherlands), 50(10), 3318-3335. https://doi.org/10.1007/s10489-020-01737-w	SF- IA	+-	Similar to the abovementioned paper
Tian, D., Yang, B., Chen, J., & Zhao, Y. (2018). A multi-experts and multi-criteria risk assessment model for safety risks in oil and gas industry integrating risk attitudes. Knowledge-based systems, 156, 62-73. https://doi.org/10.1016/j.knosys.2018.05.018	SF-IA	+-	Similar to the abovementioned paper
Tiusanen, R., Rollenhagen, C., Ove Hansson, S., Moller, N., & Holmberg, J. E. (2017). Qualitative Risk Analysis. In (pp. 463-492). Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/9781119443070.ch21	SF-IA-R&DM	+	Use cases and limitations of risk matrices discussed from various angles
Ulansky, V., & Raza, A. (2021). Generalization of minimax and maximin criteria in a game against nature for the case of a partial a priori uncertainty. Heliyon, 7(7), e07498-e07498. https://doi.org/10.1016/j.heliyon.2021.e07498	SF	-	Focus on game theory and not risk matrix design
Vaezi, A., Jones, S., & Asgary, A. (2024). Integrating Resilience into Risk Matrices: A Practical Approach to Risk Assessment with Empirical Analysis. Journal of risk analysis and crisis response, 13(4), 252-272. https://doi.org/10.54560/jracr.v13i4.411	SF – IA	+	Weighing risks with resilience as an added component
Ward, S., & Chapman, C. (2012). Uncertainty, risk and opportunity. In (pp. 43-71). Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/9781119208587.ch2	SF	+	Outlining the limitations of risk matrices considering uncertainties
Wheeler, T. L. (2008). Organization Security Metrics: Can Organizations Protect Themselves? Information security journal., 17(5), 228-242. https://doi.org/10.1080/19393550802541200	IA	-	No analysis of risk matrices
Willhite, A. M., & Norton, D. R. (1999). Establish A Baseline Assessment to Manage Risks Using Risk Matrix. INCOSE International Symposium, 9(1), 1382-1389. https://doi.org/10.1002/j.2334-5837.1999.tb00319.x	IA	-	No in depth discussion of the proposed risk matrix
Wilson, A. (2014). Inherent Flaws in Risk Matrices May Preclude Them From Being Best Practices. Journal of petroleum technology, 66(8), 106-111. https://doi.org/10.2118/0814-0106-JPT			No access
Yermalovich, P. (2020). Dashboard Visualization Techniques in Information Security.			No access
Yoe, C. (2019). Risk Assessor's Toolbox. In (pp. 273-404). United Kingdom: CRC Press. https://doi.org/10.1201/9780429021121-10	Sf	+-	High-level discussion of risk matrices

Scopus

Source	Category	Relevance	Comment
Limitations of risk assessment using risk matrices. (2009). (Vol. 129). https://doi.org/doi:10.1007/978-0-387-89014-2_4	SF	+	No access, but requested librarian
Chen, C., Zhao, Y., & Ma, B. (2024). Three-Dimensional Risk Matrix for Risk Assessment of Tailings Storage Facility Failure: Theory and a Case Study. Geotechnical and geological engineering, 42(3), 1811-1833. https://doi.org/doi:10.1007/s10706-023-02647-7	IA		No access
Entacher, M., & Sander, P. (2018). Improving: Risk matrix design using heatmaps and accessible colors. Journal of Modern Project Management, 6(1), 30-37. https://doi.org/doi:10.19255/JMPM01603	SF	+	Considerations on colour designs
Fan, C., Montewka, J., Zhang, D., & Han, Z. (2024). A framework for risk matrix design: A case of MASS navigation risk. Accident Analysis and Prevention, 199. https://doi.org/doi:10.1016/j.aap.2024.107515	SF- IA	+	Extensive article on designing a risk matrix
Flage, R., & Røed, W. (2012). A reflection on some practices in the use of risk matrices (Vol. 2). https://doi.org/doi:	SF	+	Copy requested
Hefaidh, H., & Mébarek, D. (2020). A conceptual framework for risk matrix capitalization. International journal of system assurance engineering and management, 11(3), 755-764. https://doi.org/doi:10.1007/s13198-020-00949-0	SF	+	theoretical framework of the robust risk matrices design
Krasuski, A., & Kuziora, Ł. (2018). Comparison of Risk Categorization Methods in a Multisimulation Framework (Vol. 247). https://doi.org/doi:10.1051/matecconf/201824700018	IA	+-	Application of risk matrix in fire prevention
Latvala, O.-M., Toivonen, J., Evesti, A., Sihvonen, M., & Jordan, V. (2016). Security Risk Visualization with Semantic Risk Model (Vol. 83). https://doi.org/doi:10.1016/j.procs.2016.04.247	IA	-	No risk matrix
Marhavilas, P. K., Filippidis, M., Koulinas, G. K., & Koulouriotis, D. E. (2019). The integration of HAZOP study with risk-matrix and the analytical-hierarchy process for identifying critical control-points and prioritizing risks in industry – A case study. Journal of loss prevention in the process industries, 62. https://doi.org/doi:10.1016/j.jlp.2019.103981	IA	+-	Application of risk matrix and HAZOP
Mori, Y., & Sugimoto, N. (2010). Considerations on the framework for preventive safety management with qualitative risk matrix (risk communication for an improvement of risk assessment) (Vol. 76). https://doi.org/doi:10.1299/kikaic.76.3760	R&DM	-	Some relevance, but written in Japanese
Moseman, J. A. (2024). Retrospective on the risk matrix, part 1. Process safety progress, 43(2), 270-277. https://doi.org/doi:10.1002/prs.12540	IA		No access
Nicholls, C., & Carroll, J. (2017). Is there value in a 'one size fits all' approach to risk matrices? (Vol. 2017). https://www.icheme.org/media/15553/poster-14.pdf	R&DM	+	Risk matrice standardisation
Peace, C. (2017). The risk matrix: Uncertain results? Policy and Practice in Health and Safety, 15(2), 131-144. https://doi.org/doi:10.1080/14773996.2017.1348571	SF	+	Risk matrix in relation to the ISO31001 definition
Ruan, X., Yin, Z., & Chen, A. (2013). A review on risk matrix method and its engineering application. Tongji Daxue Xuebao/Journal of Tongji University, 41(3), 381-385. https://doi.org/doi:10.3969/j.issn.0253-374x.2013.03.011	IA	-	Article written in Chinees
Sirota, L. B., Mulvihill, R., & Schweitzer, N. (2005). Communicating safety and mission success risks using risk matrices. https://doi.org/doi:			No Access
van Strien-Knippenberg, I. S., Arjangi-Babetti, H., Timmermans, D. R. M., Schrauwen, L., Fransen, M. P., Melles, M., & Damman, O. C. (2024). Communicating the results of risk-based breast cancer screening through visualizations of risk: a participatory design approach. BMC Medical Informatics and Decision Making, 24(1). https://doi.org/doi:10.1186/s12911-024-02483-6	IA	-	(to) Specific application of risk matrix
Yi, C. J., Zheng, C. Y., & Fu, Q. H. (2013). Improvement and application of risk matrix (Vol. 357). https://doi.org/doi:10.4028/www.scientific.net/AMM.357-360.2650	IA		No access
Zhang, F.-Y., Li, D.-Y., Geng, B., & Liu, Z.-L. (2015). Risk assessment of contractor support based on improved risk matrix method. Journal of Shanghai Jiaotong University (Science), 20(4), 464-467. https://doi.org/doi:10.1007/s12204-015-1650-7	IA		No access