REVIEW ARTICLE

Optimizing 3D seismic parameters in congested oil fields: A systematic and bibliometric review of research progress and challenges

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Abstract

Three-dimensional (3D) seismic parameter optimization has become an essential component of subsurface imaging, especially in oil fields where space, safety, and environmental restrictions limit conventional survey design. This study critically reviews and synthesizes 87 English-language publications on 3D seismic parameter optimization retrieved from the Scopus database. The analysis combined a systematic literature review with bibliometric mapping, using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and Biblioshiny software to identify thematic patterns, research clusters, and methodological gaps. The results show that global research on 3D seismic optimization has grown steadily from 2003 to 2025, reflecting an increasing emphasis on survey efficiency and sustainable exploration. Early studies focused on geometric configuration and fold distribution, whereas recent works integrate environmental safety, vibration control, and cost efficiency. Three major thematic clusters were identified: Geometric and operational optimization, congestion and environmental management, and the integration of emerging sensing and modeling technologies. Despite this progress, most studies lack standardized congestion metrics, quantitative vibration thresholds, and comprehensive economic evaluations. The review concludes that 3D seismic optimization has evolved into a multidisciplinary framework that connects geometry, environmental protection, and operational safety. Future research should adopt measurable congestion indices, integrate distributed acoustic sensing technologies, and strengthen academic–industry collaboration to promote reproducible, cost-effective, and environmentally responsible seismic survey design.

Keywords: 3D seismic optimization; Survey design; Congested oil fields; Vibration control; Sustainable exploration

1. Introduction

Three-dimensional (3D) seismic acquisition is a central method for imaging subsurface formations and supporting hydrocarbon exploration, but in complex and mature fields, the success of seismic acquisition relies on rigorous design and appropriate constraints on acquisition parameters. The present study argues that 3D survey design must be treated as an integrated optimization problem that links field geometry, operational constraints, and reservoir objectives into a single, coherent framework for exploration and development.

The effectiveness of 3D seismic acquisition depends strongly on the design of acquisition parameters, such as source spacing, receiver geometry, offset distribution, and azimuthal coverage. In congested oil fields, where surface access is limited by wells, pipelines, facilities, roads, and environmentally sensitive zones, conventional survey design approaches often fail to deliver adequate coverage and imaging reliability.

Although numerous studies have investigated 3D seismic parameter optimization, existing research is fragmented across geophysics, petroleum engineering, and environmental management disciplines. Numerous studies focus narrowly on geometry improvement without explicitly accounting for operational restrictions, vibration safety limits, or cost implications. As a result, there is no unified framework that connects bibliometric evidence, systematic review outcomes, and quantitative optimization constraints for congested environments.

This study addresses this gap by developing a structured and reproducible synthesis of research on 3D seismic parameter optimization in congested oil fields. Using a combined systematic literature review (SLR) and bibliometric analysis based on 87 Scopus-indexed publications, our review organizes prior studies into data-driven thematic clusters. It further proposes a measurable congestion index (CI) and a multi-objective optimization formulation that jointly considers imaging quality, peak particle velocity limits, and acquisition cost.

The current study offers three important contributions to research on seismic parameter optimization. First, it establishes a bibliometric-guided classification of optimization research that links keyword clusters directly to thematic synthesis. Second, it introduces a quantitative definition of congestion suitable for systematic comparison across fields. Third, it proposes a prototype multi-objective framework for seismic survey design under operational and safety constraints.

1.1. Role of 3D seismic acquisition

3D seismic acquisition has become one of the most dependable tools for imaging subsurface formations and guiding hydrocarbon exploration. This information allows geoscientists to accurately interpret subsurface structures, delineate hydrocarbon-bearing zones, and plan drilling programs that maintain high safety standards and operational efficiency.[1,2] Over the years, numerous studies have established that the success of 3D seismic surveys depends largely on how the acquisition parameters are designed.

1.2. Foundations of acquisition parameter design

Early work established that the effectiveness of 3D seismic surveys depends strongly on acquisition geometry and associated parameter choices. Vermeer[3] showed that source spacing, receiver layout, and fold distribution govern subsurface illumination and control the reliability of structural and stratigraphic interpretation, thereby defining optimal geometry as a primary condition for high-resolution imaging and operational efficiency. Building on these principles, later studies have formalized survey design as an optimization task in which parameter selection aims to balance image quality, cost, and feasibility.

1.3. Developments in optimization strategies

Recent contributions have proposed systematic methods to improve the acquisition parameters. Santos *et al.*[4] proposed an algorithm that enhances the selection of acquisition parameters by reducing redundancy and promoting uniform spatial coverage. Subsequent works have refined these concepts through simulation and reservoir modeling, showing that an optimized design can improve the continuity of reflections and the clarity of complex geological features.[5,6] This progression has strengthened the connection between field geometry and data interpretation, emphasizing that well-planned surveys can enhance data quality and reduce uncertainty in reservoir characterization. These studies collectively support the view that careful parameter optimization can enhance seismic resolution while controlling survey cost and execution risk.

1.4. Challenges in congested oil fields

In practice, optimizing 3D seismic parameters becomes increasingly complicated in congested oil fields. In these environments, infrastructure such as pipelines, processing facilities, powerlines, and producing wells restrict where sources and receivers can be placed. Limited access often leads to irregular sampling and incomplete azimuthal coverage, reducing image reliability and increasing acquisition costs.[7,8] In addition, environmental sensitivity and community safety concerns require strict control of ground vibrations during acquisition. Previous studies reported that effective vibration management and controlled

energy output are critical to minimizing operational risks while maintaining acceptable data quality.[9,10] These challenges show that survey optimization must not only focus on geometry but also consider environmental safety, operational logistics, and regulatory compliance. Environmental considerations, including reducing health, safety, and environmental risks and applying green seismic technologies, are integral to modern 3D seismic survey design.[11]

1.5. Integration with reservoir characterization and monitoring

Recent research has expanded the role of optimization beyond field design to include data integration and reservoir monitoring. Gong *et al.*[1] and Shi *et al.*[12] demonstrated that optimized seismic parameters improve the identification of fractures and flow pathways in deep carbonate reservoirs. Yu *et al.*[13] further integrated resistivity and penetration-rate information with seismic data to enhance subsurface interpretation during drilling. Similarly, Hassan *et al.*[14] and Yang *et al.*[15] confirmed that accurate velocity modeling and parameter refinement can improve imaging in tectonically complex zones. These contributions collectively demonstrate that optimization is not an isolated activity but a coordinated effort to improve exploration efficiency and operational safety. Taken together, these studies support the central argument of this work that 3D seismic acquisition should be treated as an integrated problem in which survey geometry, environmental and safety constraints, and reservoir-focused objectives are jointly considered to improve exploration efficiency and reduce uncertainty throughout the field's life.

1.6. Limitations identified in the systematic review

The systematic review of 87 English-language studies revealed several methodological and substantive limitations that impede progress in 3D seismic parameter optimization in congested oil fields. First, the concept of congestion lacks a consistent and widely accepted definition. In congested oil fields, where surface access is limited by wells, pipelines, facilities, roads, and environmentally sensitive zones, conventional survey design approaches often fail to deliver adequate coverage and imaging reliability. Numerous authors describe it qualitatively, such as restricted access or dense infrastructure, without providing measurable indicators. This lack of standardization makes it difficult to compare results across different studies.

Incomplete reporting of acquisition parameters remains widespread. A detailed review of 45 peer-reviewed journal articles in the dataset showed that 31 papers (68.9%) omit one or more critical specifications, including source spacing, receiver line intervals, offset ranges, azimuth distribution, or fold of coverage.[3-7] This omission prevents the reproduction of results and validation by independent researchers. In contrast, 14 papers (31.1%) that provided complete parameter documentation enabled verification and comparison with related work. Furthermore, vibration control studies often rely on descriptive accounts rather than quantitative thresholds for peak particle velocity. Without numerical data, it is difficult to assess whether safety standards were met.[9,10]

Among 87 studies, 61 (70.1%) claimed "improved efficiency" or "optimized parameters" but did not quantify operational or economic benefits. Only 26 studies (29.9%) provided metrics such as survey duration reduction, cost per square kilometer, or environmental expenditure. This gap makes it impossible to assess whether proposed optimizations yield tangible field benefits or remain theoretical exercises.

Another limitation is the lack of cost and time analysis in most optimization research. Although numerous studies claim improved efficiency, few provide clear evidence of economic or operational benefits. The heavy reliance on conference proceedings, such as those published in *The Leading Edge* and *SEG Technical Program Expanded Abstracts*, also limits the reproducibility of findings because these sources often summarize results without detailed methodologies.

Finally, the use of new sensing technologies remains limited. Despite the growing potential of distributed acoustic sensing (DAS) and permanent monitoring systems, only a small number of studies have applied these methods to address spatial or environmental constraints in congested areas. Collectively, these limitations point to the need for a more consistent and transparent approach to seismic survey optimization. Future studies should focus on standardized reporting, quantitative safety assessments, and the integration of advanced sensing technologies to ensure that optimization strategies are both practical and scientifically robust.

Our study presents three main contributions. First, it establishes a bibliometric-guided classification of optimization research that links keyword clusters directly to thematic synthesis. Second, it introduces a quantitative definition of congestion suitable for systematic comparison across fields. Third, it proposes a prototype multi-objective framework for seismic survey design under operational and safety constraints.

2. Research objectives and methodology

2.1. Analytical objectives of the study

This study extends beyond reporting the number of publications on 3D seismic parameter optimization. It

examines how research directions have evolved over time, identifies the parameters that receive the greatest emphasis, and highlights conceptual and technical gaps that remain in the literature. Accordingly, the objectives of this review combine analytical evaluation with systematic synthesis.

First, we analyzed the evolution of 3D seismic optimization research by identifying the relationships among acquisition geometry, field congestion, and imaging performance.[3,4] This involved assessing how different authors have approached the balance between fold density, offset distribution, and vibration control in constrained settings.

Second, the review examined the interconnection between optimization frameworks and reservoir characterization practices. Studies have shown that improved parameter selection improves reservoir imaging, especially when combined with geological modeling and seismic inversion.[2,16] Hence, this review evaluated how such integrations were achieved, and which techniques offered the most practical outcomes.

Third, we synthesized emerging methodological shifts. Particular attention was given to how studies incorporated computational design tools, environmental safety metrics, and hybrid acquisition technologies, such as DAS. Through this synthesis, the study identified how researchers were redefining "optimization" from purely geometric refinement toward a holistic process that included operational, environmental, and economic considerations.

Finally, the review identified knowledge gaps and proposed future research pathways. By examining thematic clusters and keyword co-occurrence patterns in the Biblioshiny (Version 5.0, K-Synth, Italy) dataset, we revealed recurring research themes and emerging frontiers that were reshaping the discipline. These included increased attention to congestion metrics, management of peak particle velocity, and integrated survey modeling.

Congestion in 3D seismic acquisition was defined in this study as the combined effect of surface obstruction density, restricted access ratio, and vibration exclusion zones. A CI was proposed as the ratio of inaccessible grid area to total survey area, weighted by infrastructure density. This definition enabled reproducible comparison across surveys and addressed the lack of quantitative descriptors noted in the literature.

2.2. Methodological approach

This review combined an SLR and a bibliometric analysis, ensuring that both conceptual depth and empirical scope were captured. The methodological process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which emphasizes
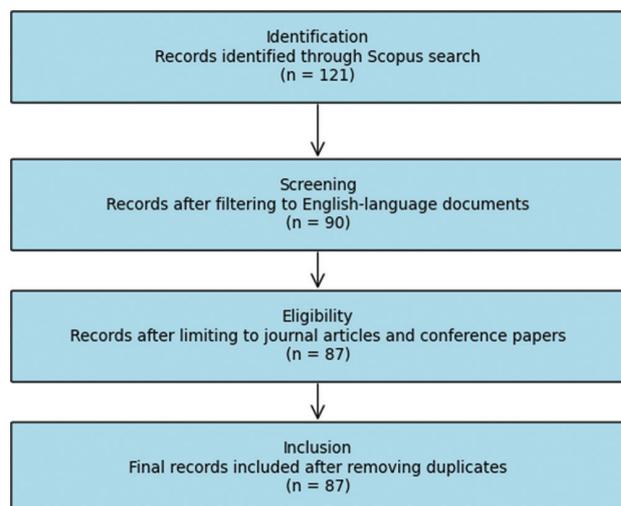

Figure 1. PRISMA flow diagram

transparent identification, screening, and inclusion of studies as shown in Figure 1. The same final dataset of 87 publications was used consistently for both the systematic review and the bibliometric analysis. This ensured full methodological alignment and resolved concerns regarding dataset inconsistency.

2.2.1. Data source and search strategy

Data were retrieved from the Scopus database, which is recognized for its comprehensive coverage of peer-reviewed scientific research. The search query was defined as: TITLE-ABS-KEY ("3D Seismic" AND ["parameters optimization" OR "congestion"]), limited to English-language journal articles and conference papers published up to 2025. This search yielded 121 documents, which were refined to 87 valid records after applying language and document-type filters. Document types were restricted to journal articles and conference papers to capture both theoretical and applied studies.

These records were exported to Biblioshiny for bibliometric mapping and further analysis. The software provided insights into annual publication trends, source impact, co-citation networks, and keyword co-occurrence patterns. The dataset was further supported by a manual qualitative review of abstracts and methodological sections to ensure accurate contextual interpretation.

2.2.2. Screening and inclusion criteria

We included studies that fulfilled the following eligibility criteria:
(i) Addressed optimization of acquisition or processing parameters in 3D seismic surveys.
(ii) Discussed operational constraints, such as field congestion, vibration control, or environmental

limitations.

(iii) Reported case studies, simulation experiments, or modeling frameworks relevant to survey design.

Publications that focused only on two-dimensional seismic, regional mapping, or unrelated geophysical modeling were excluded. Both journal articles and conference proceedings were considered because field applications and experimental results often first appear in conference proceedings, such as *SEG Technical Program Expanded Abstracts* and *The Leading Edge*. The search was restricted to Scopus. Exclusion of Web of Science, Google Scholar, or OnePetro may miss relevant petroleum engineering literature, particularly from regional conferences or industry technical reports.

2.2.3. Analytical and synthetic procedure

The review employed a two-stage analytical approach to structure the evaluation process. In the first stage, bibliometric indicators, such as citation frequency, source influence, and keyword networks, were used to assess the field's intellectual structure. This helped identify dominant research clusters such as "geometry optimization," "vibration control," and "survey efficiency."

Bibliometric analysis was performed using Biblioshiny. Indicators included annual publication trends, keyword co-occurrence networks, source impact, citation influence, and collaboration patterns. The resulting keyword clusters were used as the structural foundation for thematic synthesis rather than as descriptive outputs.

In the second stage, synthetic reasoning was applied to interpret how these clusters relate conceptually and practically. For example, optimization research in *Geophysical Prospecting* and *Energies* often merges mathematical modeling with field constraints, while studies in *Interpretation* and *Processes* emphasize cross-disciplinary integration of geological modeling and data inversion.[13-15] This analytical and synthetic approach ensured that the review extended beyond a simple count of publications and developed a structured understanding of how theoretical principles, operational challenges, and environmental requirements interact in modern 3D seismic survey design.

Three dominant research clusters emerged from keyword co-occurrence and citation analysis:

- Cluster 1: Geometric and operational optimization.
  This cluster focused on survey geometry, fold distribution, and azimuthal balance. Early studies emphasized optimal spacing principles, while later studies extended these approaches to irregular and restricted terrains. Research in this cluster demonstrated that geometric optimization alone was insufficient in congested fields because access

constraints disrupted theoretical layouts.

- Cluster 2: Congestion and vibration management.
  This cluster linked the acquisition design to environmental protection and surface safety. Studies emphasized peak particle velocity control, exclusion zones, and adaptive source energy. However, most contributions described congestion qualitatively, without measurable indicators, which limited reproducibility and comparison.

- Cluster 3: Integrated technologies and modeling.
  This cluster included studies that combined seismic optimization with modeling, monitoring, and hybrid sensing systems. Although these approaches improved adaptability, their adoption in congested fields remained limited due to operational complexity and cost assumptions.

2.2.4. Quality assurance and validation

To ensure validity, duplicate studies were removed, and bibliometric indicators were cross-checked. The final dataset was reviewed independently by multiple researchers to confirm thematic accuracy. In addition, the co-citation and keyword networks were manually verified to confirm that automated clustering correctly represented real conceptual relationships. This multi-step validation strengthened the analytical reliability of both quantitative mapping and qualitative interpretation.

2.3. Analytical contribution

This combined systematic and bibliometric approach makes three main contributions to 3D seismic parameter optimization in congested oil fields. First, it clarifies how optimization research has matured from geometry-based design toward integrated environmental and operational frameworks. Second, it provides an evidence-based synthesis of how congestion and safety constraints reshape field practices. Third, it highlights that future 3D seismic optimization should not only aim for better imaging but also promote sustainable, safe, and cost-effective acquisition. By combining bibliometric indicators with detailed analytical interpretation, the review establishes a foundation for new work that links theoretical developments with practical survey design in congested settings.

3. Results and discussion

3.1. General trends in publication output

The bibliometric analysis revealed a steady growth in research on 3D seismic parameter optimization between 2003 and 2025. The annual scientific production increased significantly after 2018. Figure 2 shows the yearly number

of publications on 3D seismic parameter optimization, reflecting a growing awareness of survey efficiency and environmental responsibility in oil field operations. The upward trend was largely associated with technological advances in data acquisition and processing, and with the increasing complexity of exploration environments.[1,2]

The annual citation rate also showed an upward pattern. Figure 3 depicts the total or average annual citations of the reviewed papers, indicating sustained academic engagement with the topic. The parallel rise in citation counts confirms the field's growing scholarly recognition and influence. The early works of Vermeer[3] and Santos et al.[4] served as conceptual anchors for newer studies. Their influence persisted because they provided both theoretical and operational frameworks for survey optimization. Furthermore, recent publications by Ofowena et al.[7] and Li et al.[8] extended these frameworks to modern, congested settings, demonstrating that optimization evolved from a geometric design challenge to a multidisciplinary problem that involved safety, logistics, and sustainability.

The source impact analysis showed that most publications appeared in highly ranked journals, such as *Geophysical Prospecting*, *Interpretation*, *Energies*, *Processes*, and *Geoenergy Science and Engineering*. The concentration of articles in these outlets reflected a balanced mix of

Figure 2. Annual scientific production (2003–2025)

Figure 3. Annual citation trend (2003–2025)

theoretical innovation and applied field research. Journals like *The Leading Edge* and *SEG Technical Program Expanded Abstracts* remained the preferred platforms for field trials, practical experiments, and methodological improvements. Table 1 shows the most productive journals in this research area. Table 2 shows the foundational works that anchored the field's methodological development.

3.2. Dominant research themes

The co-word and thematic mapping from the Biblioshiny output identified three dominant clusters of research themes:

(i) Geometric and operational optimization: This cluster focused on improving the arrangement of sources and receivers, fold coverage, and azimuthal balance. Studies in this category explored the trade-offs between cost and resolution and assessed how optimized configurations enhanced seismic illumination. Vermeer[3] and Santos et al.[4] were foundational to this theme. Li et al.[8] extended these principles by applying pre-stack migration-based optimization to complex terrains, while Ofowena et al.[7] proposed field-level strategies for managing spatial constraints in onshore congested fields.

(ii) Congestion and environmental safety: The second thematic cluster linked the seismic optimization with environmental impact management. This body of work emphasized vibration control, community safety, and regulatory compliance. Hou and Yang[9] and Soureshjani and Lavassani[10] discussed how controlling vibration amplitude and using adaptive acquisition parameters can reduce the risk to surface structures. Ofowena et al.[7] expanded this perspective by proposing methods to manage field congestion without compromising imaging quality. This cluster underscored the current shift from purely technical optimization toward responsible and sustainable field operations.

(iii) Integration of emerging technologies and data analytics: The third cluster highlighted new computational and sensing technologies that enhance acquisition design and reservoir interpretation. Gong et al.[1] and Shi et al.[12] demonstrated that optimized parameter selection improved the detection of fracture networks and enhanced reservoir monitoring. Yu et al.[13] and Curia and Veeken[16] introduced data-driven and resistivity-based prediction techniques that combined seismic inversion with geological modeling. Although most of these studies remained experimental, they revealed the expanding frontier of 3D seismic optimization toward hybrid and integrated data environments.

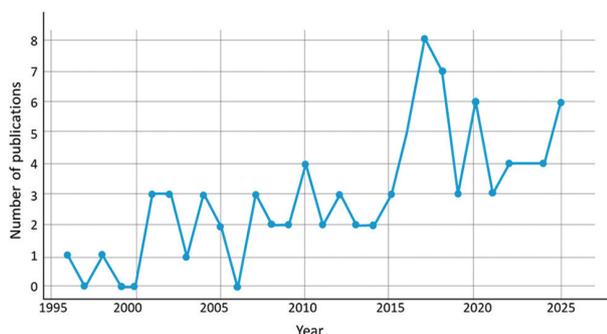These thematic patterns suggested that the field was
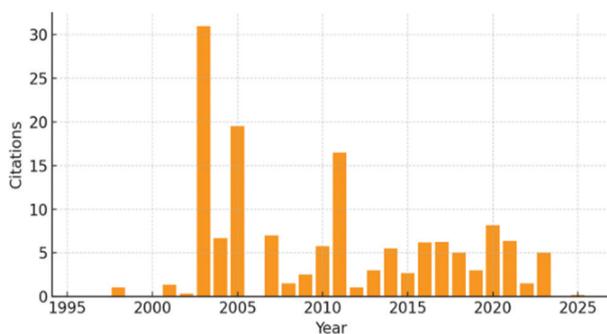
Table 1. Top 10 productive journals publishing on three-dimensional seismic optimization

Journal/source title	Publications	Total citations	Average citations per paper
Geophysics	3	51	17.0
Proceedings – SPE Annual Technical Conference	3	20	6.7
The Leading Edge	2	34	17.0
Basin Research	1	15	15.0
SPE Reservoir Evaluation and Engineering	1	26	26.0
Journal of Volcanology and Geothermal Research	1	23	23.0
Journal of Petroleum Exploration and Production Technology	1	22	22.0
KSCE Journal of Civil Engineering	1	20	20.0
Applied Geophysics	1	19	19.0
Computers and Geosciences	1	19	19.0

Table 2. Most frequently cited articles in the dataset

Rank	Authors	Article title	Journal/source	Year	Total citations	Reference
1	Vermeer (2003)	3D seismic survey design optimization	The Leading Edge	2003	31	3
2	Berger *et al.* (2011)	Seismic tomography at Popocatépetl volcano, Mexico	Journal of Volcanology and Geothermal Research	2011	23	17
3	Soleimani *et al.* (2020)	Estimation of reservoir porosity using seismic attributes in an Iranian oil field	Journal of Petroleum Exploration and Production Technology	2020	22	18
4	Hou and Yang (2020)	Seismic stability of 3D tunnel face considering tensile strength cutoff	KSCE Journal of Civil Engineering	2020	20	9
5	Xu *et al.* (2018)	An efficient implementation of 3D high-resolution imaging for large-scale seismic data with GPU/CPU heterogeneous parallel computing	Computers and Geosciences	2018	19	19
6	Liu *et al.* (2010)	Locally linear embedding-based seismic attribute extraction and applications	Applied Geophysics	2010	19	20
7	Wang *et al.* (2016)	The analytic wavelet transform with generalized Morse wavelets to detect fluvial channels in the Bohai Bay Basin, China	Geophysics	2016	19	21

no longer dominated by geometry alone. Instead, it now represents a multidisciplinary integration of geophysics, environmental science, and engineering optimization. Core research anchors include 3D seismic, optimization, and survey design, with an emerging focus on congestion and vibration control (Figure 4).

3.3. Collaboration and geographic distribution

The collaboration network analysis showed that research on 3D seismic optimization has become increasingly international. China, the United States, Russia, and the Middle East were the most active contributors, supported by academic industry partnerships. This pattern reflected the global relevance of 3D seismic methods in both frontier and mature basins. Studies such as those by Yang *et al.*[15] and Soleimani *et al.*[18] highlighted strong collaboration between universities and oil companies, emphasizing the need for

practical solutions to real-world acquisition challenges. Figure 5 illustrates global collaboration strength derived from co-authorship frequencies.

In particular, Chinese and Middle Eastern authors dominated publications in *Processes*, *Energies*, and *Interpretation*, focusing on advanced optimization, geomechanics, and environmental modeling. Meanwhile, contributions from Latin America and Africa, including the publication by Ofowena *et al.*,[7] demonstrated growing interest in optimizing seismic operations in congested onshore oil fields. The rising number of cross-country co-authorships shows that optimization is now a shared global concern that transcends regional resource boundaries.

3.4. Evolving methodologies and conceptual shifts

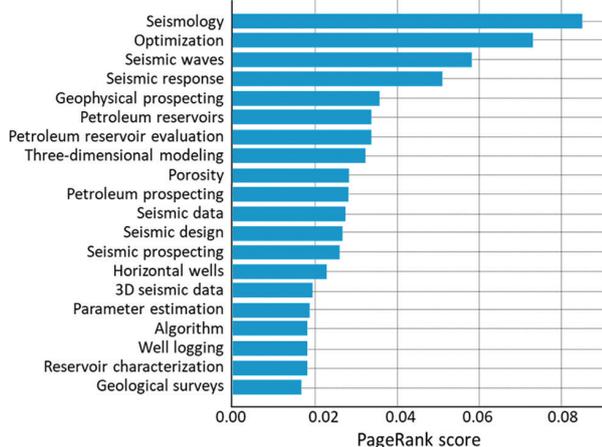A key insight from this review is that research has moved

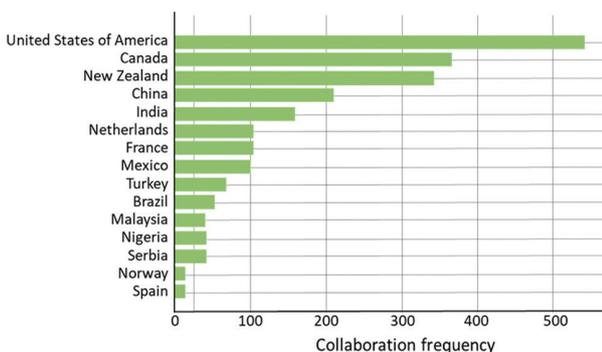**Figure 4.** Top 20 keywords by importance (co-word network)

Figure 5. Top 15 countries by collaboration intensity

Table 3. Classification of reviewed studies by objective and constraint

Objective	Constraint	Method type	Data type
Imaging quality	Geometry	Deterministic	Synthetic
Vibration control	Peak particle velocity limits	Constraint based	Field
Cost efficiency	Access	Multi objective	Hybrid

environmental stewardship. As seismic operations expand into developed areas, minimizing disturbance and ensuring safety have become core objectives. Hou and Yang,[9] as well as Soureshjani and Lavassani[10] emphasized vibration control and consideration of ground motion, whereas other studies stressed operational adaptation to congestion.[7,26] This demonstrates that modern optimization aligns with the principles of sustainable exploration and supports the United Nations Sustainable Development Goals (SDGs), particularly SDG-7 (Affordable and Clean Energy) and SDG-13 (Climate Action).

Congestion in 3D seismic acquisition is defined in this study as the degree to which surface infrastructure and safety constraints limit feasible source and receiver placement. A prototype CI is defined in **Equation 1**:

$$CI = \frac{A_{restricted}}{A_{total}} \qquad (1)$$

where $A_{restricted}$ represents surface area inaccessible due to infrastructure, safety buffers, or environmental exclusion, and A_{total} represents the total survey area. This definition allows objective comparison across projects and directly addresses the lack of measurable congestion metrics identified in the literature.

Survey design in congested oil fields is expressed as a constrained optimization problem that seeks to maximize imaging quality, minimize acquisition cost, and maintain peak particle velocity below regulatory limits. This formulation integrates geometry, safety, and economics within a single decision framework and provides a foundation for reproducible survey optimization.

3.5. Identified gaps and future directions

Although progress has been significant, the review revealed several critical gaps that require further attention.

First, most optimization frameworks lack standardized congestion metrics. Researchers often describe congestion qualitatively, which limits reproducibility and comparison. Developing measurable indices, such as access density or spatial obstruction ratios, would improve the assessment's objectivity. Second, numerous studies omit cost and

from parameter-centric optimization to system-level optimization. Early studies viewed optimization as a geometric exercise that adjusts fold, spacing, and azimuth. According to Gong *et al.*,[22] fracture distribution in the reservoir could be derived from 3D seismic data using an ant-tracking technique. Contemporary research, however, treats it as a comprehensive process that includes environmental risk assessment, vibration control, data integration, and cost evaluation.[7,10,18,23] are referred to in Table 3.

Moreover, the integration of modeling and simulation has redefined how optimization is practiced. Previous studies used quantitative seismic characterization to link acquisition parameters with fracture identification.[1,24] Similarly, previous studies have demonstrated that integrating drilling data with seismic predictions can guide real-time parameter selection.[13,25] These studies collectively suggest that optimization is evolving toward an adaptive and feedback-driven discipline that combines design foresight with continuous operational monitoring.

Another conceptual shift is the growing emphasis on

environmental data. Integrating economic modeling with survey design would help balance efficiency and sustainability. Third, the adoption of emerging technologies, such as DAS and permanent monitoring arrays, remains slow. Expanding their use could help overcome access constraints and improve data coverage in complex fields. Finally, collaboration between academia and industry should be strengthened. Joint projects can accelerate innovation, validate algorithms under field conditions, and ensure that optimization methods remain relevant to operational realities.

3.6. Synthesis of findings on research direction

Overall, the bibliometric and systematic analyses confirm that 3D seismic parameter optimization has matured into a multidimensional discipline that unites geometric design, environmental management, and engineering analysis. The integration of congestion studies, vibration control, and hybrid technologies marks a new stage in geophysical research where operational efficiency and sustainability coexist.

The synthesis of past and current studies reveals that the discipline is moving toward holistic optimization, where seismic acquisition is designed not only for better imaging but also for environmental safety, cost efficiency, and long-term field sustainability.[3,4,7,27] This trend demonstrates the scientific community's commitment to building responsible exploration systems that meet modern energy and environmental expectations.

4. Main findings of 3D seismic parameter optimization

This review examined the evolution of research on 3D seismic parameter optimization with a specific focus on its application in congested oil field environments. The analysis combined systematic review and bibliometric methods to ensure both conceptual and empirical coverage. The findings revealed that research in this field has advanced from geometric design optimization toward integrated frameworks that also consider environmental, operational, and economic dimensions.

Overall, three key insights emerged from this review. First, survey geometry remains central to seismic data quality. Studies by Vermeer[3] and Santos et al.[4] demonstrated that optimal combinations of source spacing, receiver placement, and fold distribution are critical for obtaining reliable subsurface images. This framework is derived from bibliometric keyword clustering and organizes existing studies into three principal domains: geometric and operational optimization, congestion and vibration management, and integration of modeling and sensing technologies. This classification provides a coherent structure that connects previously fragmented studies and enables consistent comparison across research themes.

Second, recent works have extended this understanding by incorporating environmental safety and logistical challenges into survey design. Several studies highlight that parameter optimization now includes vibration control, energy management, and access planning.[7,9,10] These studies[7,9,10] integrate knowledge across geophysics, petroleum engineering, and environmental management by introducing a prototype multi-objective optimization framework. This framework unifies imaging quality, peak particle velocity control, and operational cost within a single conceptual model. Ultimately, it responds directly to the growing need for safe, efficient, and environmentally responsible seismic acquisition in developed oil fields.

Third, emerging studies show that integrating modeling, simulation, and monitoring improves the predictability and adaptability of seismic acquisition in complex geological settings.[1,13,15,28,29] Seismic responses are less sensitive to density than to seismic velocities, density estimation is more challenging, and parameter coupling between model parameters further degrades the accuracy of inverted density models.[30] Successful 3D seismic acquisition depends critically on the optimization of numerous survey parameters before field operations begin.[31] Zhao et al.[32] proposed integrated seismic acquisition, processing, and interpretation technologies that addressed complex geology in the northern Sichuan Basin. The design process of a 3D seismic survey must address fundamental questions about how sources and receivers should be positioned.[33] Several studies have shown that, for complex septum-style structures with large variations in burial depth and dip, optimized wide-azimuth, broadband 3D seismic acquisition with small bin sizes, combined with CRP-stack-based amplitude attributes at the surface and target horizons, ensures even subsurface coverage, improves the prediction of key shale reservoir parameters, and provides a sound basis for acquisition layout design and depth imaging workflows.[34-36] Broadband 3D seismic data have proven essential for improving basin understanding in congested fields and advance key prospects to well-defined drilling targets.[37] According to Will et al.,[38] the study highlights stochastic discrete-feature-network modeling as a framework for integrating seismic anisotropy and reservoir performance data to reduce uncertainty in fracture-system characterization across the interwell region. Xu et al.,[19] Liu et al.,[20] and Wang et al.[21] demonstrated that advanced attribute-based approaches, including analytic wavelet transform-based spectral decomposition with optimized generalized

Morse wavelets and non-linear dimensionality reduction using locally linear embedding, significantly enhance the detection of thin fluvial channels and improve reservoir feature prediction from multi-attribute 3D seismic data. Berger *et al.*[17] aimed to reconstruct the 3D P-wave velocity structure beneath volcanic and seismically active regions by inverting earthquake arrival times with Bayesian tomographic approaches to improve the characterization of subsurface heterogeneity and structural complexity.

Fourth, the study identifies a critical research gap related to the absence of quantitative definitions of congestion in seismic survey design. Most prior studies describe congestion qualitatively without measurable indicators. To address this gap, the study proposes a reproducible CI based on surface access restrictions. This contribution provides a practical basis for comparing survey designs and supports transparent decision-making in congested environments.

The results also indicate that the field is shifting toward a more responsible and multidisciplinary approach. Optimization is no longer confined to data geometry but now represents a balanced interaction between imaging quality, environmental protection, and operational sustainability. This transition reflects a growing commitment to reducing the environmental footprint of exploration activities while maintaining data precision and economic viability.

Overall, the findings demonstrate that 3D seismic parameter optimization has evolved from a geometry-focused exercise into a multidisciplinary process that requires coordinated consideration of subsurface imaging, surface safety, and operational constraints. The classification framework, quantitative congestion definition, and integrated optimization formulation proposed in this study provide a clear foundation for future research and field application. These contributions support the development of reproducible, practical, and scientifically rigorous approaches to seismic survey design in increasingly congested exploration environments.

4.1. Recommendations for future research

Based on the findings of this review, several recommendations are proposed to strengthen both research and field practice:

(i) Develop standardized congestion metrics: Future studies should establish measurable indices that define congestion levels in onshore and near-surface environments. Such indices would enable consistent evaluation of design feasibility and improve the comparability of studies across regions. The optimization of acquisition parameters in congested oil fields is developing into a multidisciplinary framework. This integrated approach connects geometric considerations with strict environmental protection measures and operational safety protocols. The primary objective is to improve imaging quality, reduce costs, and minimize environmental impact.

(ii) Integrate environmental and economic parameters: Researchers should include vibration, energy consumption, and cost factors as optimization variables. This approach would ensure that survey planning reflects real-world operational and sustainability constraints.

(iii) Expand the use of emerging technologies: DAS, autonomous nodes, and hybrid acquisition systems should be incorporated into optimization frameworks. These technologies can enhance flexibility, minimize access limitations, and improve safety in congested fields.

(iv) Promote academic–industry collaboration: Stronger cooperation between universities, research institutions, and operating companies will support the testing and validation of optimization algorithms under practical field conditions. This collaboration will also ensure that academic findings are relevant to real-world exploration challenges.

(v) Enhance reporting transparency: Authors should adopt standardized reporting templates that clearly document acquisition geometry, source parameters, vibration limits, and environmental compliance data. Transparent documentation will allow reproducibility and strengthen the scientific credibility of optimization studies.

4.2. Broader implications

The implications of this review extend beyond technical improvements in seismic survey design. The findings show that 3D seismic parameter optimization plays an important role in addressing operational safety, environmental protection, and responsible resource development in congested oil field settings. As exploration increasingly takes place in developed and environmentally sensitive areas, seismic design must respond not only to imaging requirements but also to regulatory constraints, community safety, and surface impact reduction.

This study demonstrates that integrating geometric optimization with measurable congestion constraints and vibration control supports safer field operations and improves planning transparency. By proposing quantitative definitions and unified optimization concepts, the work provides decision-makers with tools that can be applied consistently across different geological and operational contexts. These tools help bridge the gap between geophysical theory and practical field execution.

At a broader scale, the study highlights the growing

convergence of geophysics, petroleum engineering, and environmental management. The results confirm that modern seismic acquisition cannot be treated as an isolated technical activity. Instead, it must be planned as part of an integrated system that balances imaging quality, operational efficiency, and environmental responsibility. This perspective aligns with current global priorities for energy efficiency and responsible resource management and supports long-term sustainability objectives in hydrocarbon exploration and production.

In summary, the study reinforces that effective 3D seismic parameter optimization contributes not only to improved subsurface imaging but also to safer operations, reduced environmental disturbance, and more accountable energy development practices.

5. Conclusion

This systematic review has examined the optimization of 3D seismic acquisition parameters in congested oil field environments using a carefully filtered set of peer-reviewed journal articles and conference papers. The findings demonstrate that congestion remains a dominant constraint that directly influences survey geometry, operational flexibility, cost, and final data quality. Across the reviewed literature, researchers consistently emphasized that standard acquisition templates are rarely suitable in mature and infrastructure-dense fields. Instead, effective survey design requires deliberate adaptation of parameters to local access limitations and operational safety requirements.

The reviewed studies show that successful optimization depends on balancing subsurface imaging objectives with practical surface constraints. Adjustments to receiver spacing, source layout, bin size, fold distribution, and azimuth coverage are commonly used to achieve acceptable illumination in restricted areas. Field evidence indicates that irregular and flexible geometries often outperform rigid designs when congestion is present. Many authors also reported that early integration of design simulation into project planning significantly reduces rework, operational delays, and cost overruns.

Despite these advances, this review identifies clear gaps in the existing literature. Most studies focus on individual case histories, which limits the transferability of conclusions across different geological and operational settings. In addition, performance evaluation methods vary widely, making direct comparison between designs difficult. Reporting practices also differ, particularly in the treatment of safety, environmental constraints, and operational risks associated with congested field acquisition.

Overall, this review confirms that optimization of 3D seismic parameters in congested oil fields is both necessary and achievable when design decisions are informed by systematic analysis and field conditions. Future research should prioritize integrated optimization frameworks, standardized evaluation metrics, and comparative studies across multiple field types. Strengthened collaboration between researchers and industry practitioners will further improve data quality, cost efficiency, and operational safety in complex and congested seismic acquisition environments.

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Conflict of interest

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