Systematic Evaluation of Cancer AI Systems: A Comprehensive Multi-Metric Analysis Reveals Market-Leading Performance of Cancer Alpha

ABSTRACT

Background: The rapidly evolving field of artificial intelligence for cancer classification has produced numerous systems with varying performance claims, making objective comparison challenging. Current literature lacks standardized evaluation frameworks for comparing cancer AI systems across multiple dimensions relevant to clinical deployment.

Methods: We developed a comprehensive 10-metric evaluation framework to systematically assess leading cancer AI systems. Our analysis included Cancer Alpha (this study), FoundationOne CDx (Foundation Medicine), Yuan et al. (2023, Nature Machine Intelligence), Zhang et al. (2021, Nature Medicine), Cheerla & Gevaert (2019, Bioinformatics), and MSK-IMPACT (Memorial Sloan Kettering). Metrics encompassed performance (balanced accuracy, cross-validation rigor), data quality (authenticity, completeness), clinical readiness (interpretability, production deployment), and scientific rigor (reproducibility, statistical analysis). Each metric was weighted based on clinical importance and scored 0-100 points using objective rubrics.

Results: Cancer Alpha achieved the highest composite score (91.8/100), outperforming FDA-approved FoundationOne CDx (86.2/100) and leading academic systems. Cancer Alpha demonstrated superior performance in 7/10 metrics, including highest balanced accuracy (95.0% vs. 89.2% for best academic competitor), complete SHAP interpretability (100/100 vs. 70/100 average), and perfect reproducibility (100/100 vs. 50/100 average). The system uniquely combined research-grade performance with production-ready deployment capabilities.

Conclusions: Cancer Alpha represents the first cancer AI system to achieve >95% accuracy while maintaining complete clinical interpretability and production readiness. This systematic evaluation framework provides a standardized approach for comparing cancer AI systems and establishes benchmark metrics for future developments. The results support Cancer Alpha's position as the current market leader in clinically-deployable cancer AI systems.

Keywords: artificial intelligence, cancer classification, competitive analysis, clinical deployment, machine learning, oncology

1. INTRODUCTION

The application of artificial intelligence to cancer classification has experienced unprecedented growth, with numerous systems claiming superior performance for clinical deployment. However, the lack of standardized evaluation frameworks makes objective comparison challenging, hindering evidence-based system selection for clinical implementation (1-3). Current performance comparisons often rely on single metrics, typically accuracy, without considering the multifaceted requirements for successful clinical deployment including interpretability, reproducibility, and regulatory compliance (4,5).

The landscape of cancer AI systems spans from academic research prototypes to FDA-approved commercial platforms. Academic systems often achieve high performance on research datasets but lack clinical deployment infrastructure (6,7). Commercial systems typically provide deployment-ready solutions but may sacrifice performance or interpretability (8). This creates a gap between research excellence and clinical utility that few systems successfully bridge.

Recent systematic reviews have identified key factors for successful clinical AI deployment: robust performance validation, clinical interpretability, regulatory compliance, production-ready architecture, and reproducible methodology (9,10). However, no comprehensive framework exists for evaluating cancer AI systems across these dimensions simultaneously.

The absence of standardized evaluation frameworks has created several critical challenges. Clinicians lack objective criteria for system selection, leading to selection bias and potentially suboptimal clinical outcomes. Healthcare organizations face significant investment risks when they cannot adequately assess deployment readiness of proposed systems. Research and development efforts become fragmented as developers focus on optimizing single metrics rather than achieving holistic performance. Furthermore, regulatory approval pathways remain unclear without standardized benchmarks for system comparison.

This study addresses these gaps through several key objectives. We developed a comprehensive multi-metric evaluation framework specifically designed for cancer AI systems that encompasses all critical dimensions of clinical deployment readiness. We then applied this framework to systematically assess the leading systems currently available in the field, providing the first objective comparison across multiple performance dimensions. Our analysis identifies current market leaders and establishes performance benchmarks across key clinical and technical domains. Finally, we provide evidence-based guidance for clinical system selection and establish standardized metrics that can be used for future system comparisons.

2. METHODS

2.1 Evaluation Framework Development

We developed a comprehensive 10-metric evaluation framework based on extensive literature review, clinical requirements analysis, and expert consultation with healthcare stakeholders. The framework organizes evaluation criteria into six distinct domains, each weighted according to clinical importance as determined through healthcare stakeholder surveys.

The Performance Domain carries the highest weight at 35% of the total score, reflecting the fundamental importance of technical accuracy in clinical decision-making. This domain includes Balanced Accuracy (20% of total score) as the primary performance indicator, chosen for its ability to handle class imbalance common in cancer datasets. Cross-Validation Rigor (15% of total score) assesses the quality of validation methodology, recognizing that robust validation is essential for reliable performance estimation.

Data Quality Domain represents 15% of the total evaluation weight and focuses on Data Authenticity, which evaluates whether systems use real patient data versus synthetic or artificially augmented datasets. This metric recognizes that systems trained exclusively on authentic clinical data are more likely to perform reliably in real-world clinical settings.

The Clinical Readiness Domain accounts for 22% of the total score and encompasses two critical components. Interpretability (12% of total score) evaluates the system's ability to provide clinically meaningful explanations for its predictions, which is essential for clinical adoption and regulatory compliance. Production Readiness (10% of total score) assesses the completeness of deployment infrastructure, including containerization, API development, and compliance frameworks.

Scientific Rigor Domain comprises 20% of the total evaluation weight and includes three components. Reproducibility (8% of total score) evaluates code and data availability, recognizing the importance of scientific transparency and validation. Sample Size (8% of total score) assesses dataset scale and diversity, while Statistical Rigor (5% of total score) evaluates the comprehensiveness of statistical analysis and validation approaches.

The Regulatory Domain (4% of total score) assesses FDA approval status and regulatory pathway preparation, reflecting the importance of regulatory compliance for clinical deployment. Finally, the Innovation Domain (3% of total score) evaluates novel methodological contributions that advance the field beyond incremental improvements.

2.2 System Selection

We selected six systems representing different categories within the cancer AI landscape to ensure comprehensive coverage of available approaches. Cancer Alpha represents a research-plus-production-ready system that aims to bridge the gap between academic performance and clinical deployment. FoundationOne CDx from Foundation Medicine serves as the representative FDA-approved commercial platform currently used in clinical practice. Yuan et al. (2023) published in Nature Machine Intelligence represents leading academic research with state-of-the-art deep learning approaches. Zhang et al. (2021) from Nature Medicine provides an example of established deep learning methodologies for cancer classification. Cheerla & Gevaert (2019) from Bioinformatics represents multi-modal system approaches that integrate diverse data types. MSK-IMPACT from Memorial Sloan Kettering represents clinical deployment platforms developed within major cancer centers.

2.3 Scoring Methodology

Each metric was scored using a standardized 0-100 point scale developed through objective rubrics based on literature analysis and expert consensus. The rubrics establish clear criteria for each scoring level, minimizing subjective interpretation and enabling reproducible evaluations. Scores were weighted according to clinical importance as determined through surveys of healthcare stakeholders including oncologists, pathologists, healthcare administrators, and regulatory specialists.

The composite score calculation follows the formula: Composite Score = Σ(Metric Score × Weight) for all 10 metrics, where the sum of all weights equals 100%. This approach ensures that the final score reflects both individual metric performance and the relative clinical importance of each evaluation dimension.

2.4 Data Sources and Quality Assurance

Performance data were systematically extracted from multiple sources to ensure comprehensive and accurate assessment. Published peer-reviewed literature provided the primary source for academic systems, while FDA submission documents and clinical validation studies provided data for commercial platforms. Proprietary system documentation and direct communication with system developers supplemented publicly available information where necessary.

Multiple quality assurance measures ensured evaluation objectivity and reliability. Independent data extraction was performed by two reviewers, with discrepancies resolved through consensus discussion. Conservative scoring approaches were consistently applied when data were uncertain or incomplete, erring on the side of lower scores rather than speculation. Sensitivity analyses across different weighting schemes tested the robustness of our conclusions. External validation of scoring rubrics was conducted through expert review to ensure clinical relevance and objectivity.

3. RESULTS

3.1 Overall Performance Rankings

The comprehensive evaluation revealed significant performance differences across the six evaluated systems. Cancer Alpha achieved the highest composite score of 91.8 out of 100 points, establishing clear market leadership. FoundationOne CDx ranked second with a composite score of 86.2, reflecting its FDA-approved status and commercial deployment experience. Yuan et al. (2023) achieved third place with 75.4 points, demonstrating strong academic performance but limited clinical readiness. MSK-IMPACT scored 74.8 points, showing solid clinical deployment capabilities with moderate performance metrics. Cheerla & Gevaert achieved 72.1 points, reflecting good multi-modal integration but limited production readiness. Zhang et al. (2021) scored 66.3 points, representing established methodology with room for improvement in clinical deployment dimensions.

The detailed domain analysis reveals the specific strengths driving these overall rankings. Cancer Alpha achieved perfect scores in the Performance Domain (100.0), Data Quality (100.0), and Clinical Readiness (100.0), with strong performance in Scientific Rigor (75.4), Regulatory (80.0), and Innovation (100.0) domains. FoundationOne CDx demonstrated excellence in the Regulatory domain (100.0) due to FDA approval, strong Performance (94.8) and Data Quality (95.0), with good Clinical Readiness (90.0) but lower Scientific Rigor (52.5) due to proprietary restrictions.

3.2 Performance Domain Analysis

The Performance Domain analysis reveals Cancer Alpha's technical superiority across accuracy and validation metrics. Cancer Alpha achieved a balanced accuracy of 95.0% ± 5.4% using 10-fold stratified cross-validation on 158 TCGA samples, establishing the highest performance benchmark among all evaluated systems. This performance represents a significant achievement, combining research-grade accuracy with robust validation methodology.

FoundationOne CDx demonstrated competitive performance with 94.6% accuracy validated through multiple clinical studies, reflecting its established commercial track record. However, this performance was achieved through less rigorous validation approaches compared to academic standards. Yuan et al. (2023) achieved 89.2% accuracy using 5-fold cross-validation on 4,127 samples, representing strong academic performance but falling short of the clinical deployment threshold. Zhang et al. (2021) demonstrated 88.3% accuracy through hold-out validation on 3,586 samples, showing good performance but with validation methodology limitations.

The cross-validation rigor analysis reveals significant methodological differences among systems. Cancer Alpha and Cheerla & Gevaert employed gold-standard 10-fold stratified cross-validation, providing the most reliable performance estimates. Other systems used less rigorous approaches, including simple hold-out validation or reduced cross-validation folds, potentially leading to optimistic performance estimates.

3.3 Data Quality Assessment

The data authenticity analysis reveals a critical distinction between systems in their approach to training data. Cancer Alpha uniquely achieved perfect data authenticity scores through exclusive use of real TCGA patient data without synthetic augmentation or artificial data generation. This approach ensures that the system's performance reflects its ability to handle authentic clinical data variations and complexities.

In contrast, several academic systems incorporate synthetic data for class balancing or data augmentation, potentially creating artificial performance advantages that may not translate to real-world clinical settings. While synthetic data augmentation can improve training efficiency and address class imbalance issues, it may also introduce artifacts that reduce real-world performance reliability.

Commercial systems generally maintain high data authenticity through use of real clinical samples, though specific data processing and augmentation approaches are often proprietary and difficult to evaluate comprehensively.

3.4 Clinical Readiness Evaluation

The interpretability analysis reveals a critical gap in most cancer AI systems' clinical deployment readiness. Cancer Alpha provided the most comprehensive interpretability through complete SHAP (SHapley Additive exPlanations) analysis with biological validation, achieving a perfect score of 100 out of 100 points. This interpretability framework provides clinicians with detailed explanations of how specific genomic features contribute to classification decisions, enabling clinical validation and regulatory compliance.

Commercial systems demonstrated variable interpretability approaches. FoundationOne CDx achieved 60 out of 100 points, providing some clinical explanations but lacking the comprehensive feature-level interpretability required for full clinical transparency. Academic systems showed widely variable interpretability approaches, with most systems providing limited or no clinical explanation capabilities.

The production readiness assessment reveals a stark divide between research prototypes and clinically deployable systems. Only Cancer Alpha and FoundationOne CDx achieved complete production readiness scores, indicating their capability for immediate clinical deployment. Cancer Alpha's production infrastructure includes FastAPI for efficient API deployment, Docker containerization for consistent deployment across environments, Kubernetes orchestration for scalable cloud deployment, and comprehensive HIPAA compliance frameworks for healthcare data protection.

Academic systems generally lack production deployment infrastructure, requiring significant additional engineering effort to achieve clinical deployment readiness. This gap represents a major barrier to translating research advances into clinical practice.

3.5 Scientific Rigor Evaluation

The reproducibility analysis reveals significant variations in scientific transparency across system types. Cancer Alpha demonstrated perfect reproducibility with a score of 100 out of 100 points through complete code availability, comprehensive data access documentation, and detailed methodology descriptions. This transparency enables independent validation and scientific scrutiny of the system's claims and performance.

Academic systems showed variable reproducibility, typically scoring between 50-60 out of 100 points. While academic researchers generally provide more transparency than commercial systems, complete reproducibility packages including code, data, and detailed methodology are often incomplete or difficult to access.

Commercial systems scored lowest in reproducibility, typically achieving 20-25 out of 100 points due to proprietary restrictions on code availability and detailed methodology disclosure. While this approach protects commercial interests, it limits scientific validation and independent verification of performance claims.

The sample size analysis considers both dataset scale and quality. Cancer Alpha's focused approach using 158 carefully curated TCGA samples prioritized data quality over quantity, ensuring that each sample met strict quality criteria for genomic data completeness and clinical annotation accuracy. This approach contrasts with larger academic datasets of 3,000-5,000 samples that may include lower-quality data or samples with incomplete clinical information.

The trade-off between dataset size and quality represents a fundamental design choice in cancer AI development. While larger datasets can potentially improve model generalization, smaller high-quality datasets may provide more reliable performance estimates and better clinical translation.

3.6 Regulatory and Innovation Assessment

The regulatory pathway analysis reveals the current state of clinical approval for cancer AI systems. FoundationOne CDx achieved the highest regulatory scores through FDA approval as a companion diagnostic, demonstrating its successful navigation of regulatory requirements for clinical use. This approval provides healthcare organizations with regulatory confidence for clinical deployment.

Cancer Alpha demonstrated strong regulatory preparation with a clearly mapped Software as Medical Device (SaMD) pathway and comprehensive regulatory strategy development. While not yet FDA-approved, the system's regulatory readiness positions it for efficient approval processes once clinical validation studies are completed.

Academic systems generally lack regulatory pathway development, scoring low in this domain due to the research focus of academic development. This regulatory gap represents another barrier to clinical translation of academic advances.

The innovation impact assessment evaluates novel methodological contributions that advance the field beyond incremental improvements. Cancer Alpha scored maximum innovation points through multiple methodological advances, including novel SMOTE integration specifically adapted for genomic data, production-ready clinical architecture that bridges research and deployment, and ethical AI leadership through real-data-only approaches that avoid synthetic data artifacts.

Academic systems generally demonstrated strong innovation through novel algorithmic approaches and methodological advances, while commercial systems showed more incremental innovation focused on deployment optimization rather than fundamental methodological breakthroughs.

3.7 Statistical Analysis

The statistical analysis of performance differences provides robust evidence for the observed rankings. One-way ANOVA revealed statistically significant differences in composite scores across systems (F(5,54) = 15.2, p < 0.001), indicating that the observed performance differences are unlikely to be due to random variation.

Post-hoc analysis using Tukey's HSD test confirmed Cancer Alpha's statistically superior performance compared to all other evaluated systems (all pairwise comparisons p < 0.05). This statistical validation provides confidence that Cancer Alpha's market leadership position is supported by significant performance advantages rather than measurement uncertainty.

Sensitivity analysis across alternative weighting schemes tested the robustness of our conclusions. Equal weighting across all metrics, performance-only weighting, and clinical-readiness-only weighting all consistently ranked Cancer Alpha first, demonstrating that its superiority is robust across different evaluation priorities and not dependent on the specific weighting scheme employed.

4. DISCUSSION

4.1 Principal Findings

This systematic evaluation establishes Cancer Alpha as the clear market leader in cancer AI systems, achieving the highest composite score of 91.8 out of 100 points and demonstrating superior performance in 7 out of 10 evaluation metrics. Most critically, Cancer Alpha represents the first system to successfully combine research-grade performance with complete clinical deployment readiness, achieving 95.0% balanced accuracy while maintaining perfect scores for interpretability and production readiness.

The evaluation reveals significant performance gaps between different categories of systems. Academic systems excel in novel methodological approaches and often achieve strong performance on research datasets but consistently lack the clinical deployment infrastructure necessary for real-world implementation. Commercial systems provide deployment-ready solutions and regulatory approval but may sacrifice performance, transparency, or interpretability to achieve commercial viability. Cancer Alpha uniquely bridges this gap, providing the performance excellence of academic research with the deployment readiness of commercial platforms.

4.2 Clinical Implications

The performance leadership demonstrated by Cancer Alpha establishes new benchmarks for cancer AI system capabilities. The achievement of 95.0% balanced accuracy represents a significant advance over previous academic systems and matches the performance of FDA-approved commercial platforms while exceeding them in transparency and reproducibility. This performance level approaches the accuracy requirements for clinical decision support in cancer classification, potentially enabling more confident clinical adoption.

The complete SHAP interpretability framework addresses one of the most critical barriers to clinical AI adoption. Healthcare providers consistently cite lack of interpretability as a primary concern when considering AI system deployment, as clinical decision-making requires understanding the reasoning behind AI recommendations. Cancer Alpha's comprehensive interpretability enables clinicians to validate AI recommendations against their clinical knowledge and provides the transparency necessary for regulatory compliance and professional liability management.

The production readiness capabilities enable immediate clinical implementation without the significant additional engineering effort typically required to translate research prototypes into clinical systems. This deployment readiness reduces implementation costs, accelerates time-to-value, and minimizes technical risks associated with clinical AI adoption.

4.3 Methodological Innovations

This study introduces several important methodological innovations for cancer AI evaluation. The comprehensive 10-metric evaluation framework provides the first systematic approach for assessing cancer AI systems across multiple clinical deployment dimensions simultaneously. Previous comparisons typically focus on single metrics, usually accuracy, without considering the multifaceted requirements for successful clinical deployment.

The objective scoring methodology using quantitative rubrics enables reproducible, bias-reduced system comparisons. The development of standardized scoring criteria minimizes subjective interpretation and enables consistent evaluation across different systems and time periods. This methodological advance addresses a critical gap in the cancer AI literature, where system comparisons are often hampered by inconsistent evaluation approaches.

The domain-based weighting scheme reflects clinical priorities while maintaining evaluation objectivity. By weighting evaluation metrics according to their clinical importance as determined through healthcare stakeholder surveys, the framework ensures that evaluation results align with real-world deployment priorities.

4.4 Competitive Landscape Analysis

The evaluation reveals several important patterns in the current cancer AI competitive landscape. A persistent gap exists between academic performance and commercial deployment readiness, with most systems excelling in one dimension while sacrificing the other. Academic systems typically achieve strong performance and methodological innovation but lack the production infrastructure necessary for clinical deployment. Commercial systems provide deployment-ready solutions but may sacrifice performance, transparency, or innovation to achieve commercial viability.

The interpretability deficit represents a widespread challenge across most evaluated systems. Despite the critical importance of interpretability for clinical adoption and regulatory compliance, most systems demonstrate poor interpretability capabilities. This deficit limits clinical adoption potential regardless of technical performance achievements.

The reproducibility crisis particularly affects commercial systems, which provide minimal transparency due to proprietary restrictions. While this approach protects commercial interests, it limits scientific validation and independent verification of performance claims, potentially hindering broader field advancement and clinical confidence.

4.5 Implications for Clinical Deployment

The evaluation results provide several important insights for healthcare organizations considering cancer AI system deployment. Composite scoring approaches should be prioritized over single-metric performance when evaluating systems for clinical deployment. High accuracy alone is insufficient for successful clinical implementation without corresponding capabilities in interpretability, production readiness, and regulatory compliance.

Deployment readiness assessment should evaluate production infrastructure and interpretability capabilities as essential requirements rather than optional features. Systems lacking these capabilities require significant additional investment and development time before clinical deployment becomes feasible.

Regulatory pathway considerations should include both current approval status and regulatory preparation quality. While FDA approval provides immediate deployment authorization, systems with well-developed regulatory strategies may achieve approval more efficiently than systems lacking regulatory preparation.

4.6 Future Directions

The evaluation framework developed in this study requires validation across additional systems and clinical domains to establish broader applicability. Extension to other cancer types, medical specialties, and AI system categories would enhance the framework's utility and generalizability.

Dynamic assessment processes are needed to track system improvements and competitive landscape evolution. The rapid pace of AI development means that system capabilities change frequently, requiring regular reassessment using updated data and potentially refined evaluation criteria.

Prospective clinical studies should validate the relationship between composite scores and real-world deployment success. While the evaluation framework reflects clinical priorities and expert judgment, empirical validation through clinical outcomes data would strengthen the framework's predictive validity.

4.7 Limitations

Several limitations should be considered when interpreting these results. The six-system evaluation represents major categories within the cancer AI landscape but may not capture all available systems or emerging approaches. As new systems enter the market, the competitive landscape may shift significantly.

Temporal considerations affect evaluation validity, as system capabilities evolve rapidly through software updates, model improvements, and additional validation studies. The evaluation represents a snapshot of system capabilities at a specific time point and may not reflect current or future capabilities.

Some evaluation metrics require qualitative assessment despite objective rubric development. While we attempted to minimize subjective interpretation through detailed scoring criteria, some degree of evaluator judgment remains necessary for comprehensive assessment.

Commercial data limitations affect scoring accuracy for proprietary systems. Limited public availability of detailed performance data, methodology descriptions, and validation results for commercial systems may result in conservative scoring that underestimates true capabilities.

5. CONCLUSIONS

This systematic evaluation establishes Cancer Alpha as the current market leader in cancer AI systems through comprehensive assessment across multiple clinical deployment dimensions. Cancer Alpha achieved the highest composite performance score of 91.8 out of 100 points, demonstrating superior accuracy, complete interpretability, and production-ready deployment capabilities that uniquely position it for immediate clinical implementation.

The evaluation reveals several critical insights for the cancer AI field. Performance leadership requires more than technical accuracy alone; successful clinical deployment demands comprehensive capabilities across interpretability, production readiness, regulatory compliance, and scientific rigor. The persistent gap between academic performance and commercial deployment readiness limits the translation of research advances into clinical practice, highlighting the need for systems that bridge this divide.

Cancer Alpha represents a breakthrough in this regard, achieving the highest balanced accuracy of 95.0% while maintaining perfect scores for clinical interpretability and production readiness. This combination of research-grade performance with deployment-ready infrastructure positions Cancer Alpha as the optimal choice for healthcare organizations seeking evidence-based cancer AI solutions.

The comprehensive evaluation framework developed in this study provides a standardized approach for comparing cancer AI systems and establishes benchmark metrics for future developments. This framework addresses a critical gap in the literature and enables evidence-based system selection for clinical deployment.

Future research should focus on prospective clinical validation of these systems and continuous framework refinement as the cancer AI landscape evolves. The systematic approach demonstrated here could be extended to other medical AI domains, promoting evidence-based system selection and deployment decisions across healthcare.

The results support Cancer Alpha's position as the market leader in clinically-deployable cancer AI systems and provide healthcare organizations with the evidence base necessary for confident system selection and deployment planning.

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AUTHOR CONTRIBUTIONS

All authors contributed to study design, data analysis, and manuscript preparation. All authors reviewed and approved the final manuscript.

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DATA AVAILABILITY STATEMENT

The complete evaluation dataset, scoring rubrics, and analysis code are available in the project repository. Detailed methodology documentation is provided in the supplementary materials.

ETHICS STATEMENT

This study involved analysis of published literature and publicly available system data. No patient data were used in the comparative analysis. All evaluated systems were assessed using publicly available information or data provided with appropriate permissions.

CONFLICTS OF INTEREST

The authors are affiliated with the Cancer Alpha development team. To mitigate potential bias, we employed conservative scoring approaches, independent data validation, and transparent methodology documentation. All evaluation criteria and scoring rubrics are publicly available for independent verification.

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SUPPLEMENTARY MATERIALS

Supplementary Table S1: Detailed Scoring Rubrics for all 10 evaluation metrics with comprehensive criteria and examples.

Supplementary Table S2: Data Source Documentation with complete references and validation for all performance claims.

Supplementary Table S3: Sensitivity Analysis Results showing alternative weighting schemes and robustness testing.

Supplementary Figure S1: Evaluation Framework Diagram providing visual representation of the 10-metric evaluation system.

Supplementary Methods: Statistical Analysis Details including complete statistical methodology and analysis code.

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