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Research on FAIR Data Assessment Models and Tools: Postprint

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Abstract

[Purpose/Significance] This paper presents a comparative analysis of FAIR data assessment models and tools, aiming to provide stakeholders in data construction and data management processes with a reference for evaluating FAIR data compliance. [Method/Process] Through literature review and investigation of model documentation, seven international indicator models and tools for assessing FAIR data compliance are introduced from two dimensions: assessment indicators and assessment methods. A comparative analysis approach is adopted to systematically evaluate these models and tools across six aspects: types of assessment methods, degree of automation, operability, quantity and distribution of indicators, metadata indicator configuration, and indicator clarity. [Results/Conclusion] Based on the comparative evaluation findings, a solution combining “FAIRsFAIR Data Object Assessment + FAIR Data Maturity Model” is proposed for the selection and application of FAIR data assessment models and tools.

Full Text

Preamble

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Research on FAIR Data Assessment Models and Tools
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Abstract

[Purpose/Significance] This paper compares and analyzes FAIR data assessment models and tools to provide references for stakeholders in data construction and management to evaluate FAIR compliance. [Method/Process] Through

literature review and analysis of model texts, this study introduces seven international metric models and tools for assessing FAIR data compliance from two perspectives: assessment indicators and assessment methods. A comparative analysis method is employed to evaluate these models and tools across six dimensions: assessment method type, automation level, operability, indicator quantity and distribution, metadata indicator settings, and indicator clarity. **[Result/Conclusion]** Based on the comparison and analysis, a solution of “FAIRsFAIR Data Object Assessment + FAIR Data Maturity Model” is proposed for selecting and applying FAIR data assessment models and tools.

Keywords: FAIR assessment; FAIR compliance; FAIR maturity; FAIR metrics; data FAIRification; FAIR principles

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The FAIR principles—Findable, Accessible, Interoperable, and Reusable—were officially released by the FORCE11 organization in 2016, aiming to enhance the openness, transparency, and reusability of scientific data. FAIR provides a common framework and guidance for the optimal state that data should achieve during data construction and management processes (optimal discovery and reuse). Throughout these processes, it is necessary to continuously understand the degree of FAIR compliance (or FAIR adherence, FAIR implementation level) to identify areas requiring further improvement. Consequently, establishing clear, discriminative, measurable, and universally applicable assessment indicators has become an urgent need. In recent years, some international organizations have begun to introduce corresponding tools and methods to assess the degree of FAIR compliance. This paper primarily introduces the FAIR Metrics Group, the Dutch Data Archiving and Networked Services (DANS), the Australian Research Data Commons (ARDC), the Commonwealth Scientific and Industrial Research Organization (CSIRO), the Research Data Alliance (RDA), FAIRsFAIR (Fostering FAIR Data Practices in Europe), and the European Open Science Cloud (EOSC), among other organizations that have proposed seven assessment models and tools for evaluating FAIR compliance. These provide references for data creators (such as researchers), data managers (such as data centers and libraries), data service providers (such as data repositories), and re-

search funding agencies to assess the degree of FAIR compliance and understand the FAIR status of data, thereby promoting the FAIRification level of data.

1. Current Research Status

As the FAIR principles gain traction, an increasing number of institutions have begun to accept and support them. International research has primarily focused on three aspects: (1) Introducing and interpreting the FAIR principles, such as the “FAIR Principles Interpretation” published on the GOFAIR website, M.D. Wilkinson et al.’s explanation of the FAIR principles, and A. Jacobsen et al.’s article-by-article interpretation with implementation considerations. (2) Researching how to implement FAIR principles, such as A. Jacobsen et al.’s proposed generic workflow for digital resource FAIRification, GoFAIR’s comprehensive methodology, processes, and tools for FAIRifying data and services in specific domains, and guidance documents from various groups and institutions, including the European Commission’s report “Turning FAIR into Reality,” which provides 27 detailed recommendations and actions for different stakeholders, and the European Open Science Cloud FAIR Working Group’s six recommendations for advancing FAIR implementation. (3) Applying FAIR principles to assess data repositories, such as M. Hahnel and V. Dan’s survey of FAIR compliance in 10 data repositories, and A. Dunning et al.’s analysis of FAIR compliance in over 40 data repositories. However, these analyses did not employ a formal assessment model or criteria; instead, authors evaluated compliance based on repository help pages, metadata records, and related materials, making the assessment process rather subjective. Therefore, establishing clear, discriminative, measurable, and universally applicable assessment indicators to evaluate the degree of FAIR implementation has become an urgent need. To address this, the FAIR Metrics Group, DANS, ARDC, CSIRO, RDA, FAIRs-FAIR, and EOSC have each proposed their own models or tools for assessing FAIR implementation levels.

Domestic research on FAIR data assessment is relatively limited, primarily focusing on introducing the principles. For example, in 2019, Duan Qingyu and Wang Xiaoguang introduced the FAIR principles and investigated their implementation in three representative data publishing platforms: Peking University’s Open Research Data Platform, DANS, and the HumNum platform for humanities and social sciences. Yang Xiaolin et al. studied the application of FAIR criteria in biomedical data standards. Subsequently, Xing Wenming et al. and Song Jia et al. provided systematic and comprehensive introductions to the principles. Additionally, the English journal *Data Intelligence*, co-sponsored by the National Science Library of the Chinese Academy of Sciences and MIT Press, published a special issue on FAIR in its 2020 Volume 1-2, featuring 29 papers covering FAIR concepts, implementation, and case studies, providing a comprehensive resource for understanding FAIR.

Analysis of domestic and international research reveals that assessing the degree of FAIR implementation or understanding data FAIR compliance is a crucial

aspect of FAIR implementation and application, receiving increasing attention from international organizations that have proposed various assessment frameworks and methods. This paper introduces seven major international metric models and tools for assessing FAIR implementation levels, providing references for stakeholders in data construction and management.

Since the seven assessment tools introduced below are largely based on the FAIR principles for their indicator settings, readers may refer to Xing Wenming et al. for details on the 15 FAIR principle indicators, which will not be reiterated here.

2. International FAIR Data Assessment Models and Tools

2.1 Self-Assessment Tools Using Web Checklists/Forms/Lists or Questionnaires

The primary self-assessment tools using web checklists, forms, lists, or questionnaires include the FAIR Compliance Assessment Metrics, FAIRdat, the FAIR Data Assessment Tool, and the 5-Star Data Assessment Tool. The FAIR Compliance Assessment Metrics were proposed in 2018 by the FAIR Metrics Group, independently established by M.D. Wilkinson and other FAIR principle originators. FAIRdat was developed by DANS. The FAIR Data Assessment Tool was developed in summer 2017 by ARDC, the National eResearch Collaboration Tools and Resources Project (NeCTAR Project), and Research Data Services (RDS) to assess dataset FAIR compliance, primarily targeting data librarians and IT staff but also applicable to software engineers and researchers. The 5-Star Data Assessment Tool was developed by CSIRO based on a data rating system.

Except for the 5-Star Data Assessment Tool, the other three tools set assessment indicators based on the FAIR principles (see Table 1). The FAIR Metrics Group's FAIR Compliance Assessment Metrics include 14 indicators that correspond to the 15 FAIR principles. FAIRdat also bases its indicators on the FAIR principles, designing specific measurement indicators for the Findable, Accessible, and Interoperable dimensions but none for the Reusable dimension; its score is the average of the first three dimensions. The FAIR Data Assessment Tool similarly sets assessment indicators based on the four FAIR dimensions. The 5-Star Data Assessment Tool includes 14 indicators that do not fully align with the FAIR principles; some correspond to FAIR principles while others extend beyond them, such as indicators for stewardship, update and maintenance, and usage.

In terms of assessment methodology, these self-assessment tools set several questions under each indicator with various response options, generating assessment results through question responses. The assessment format uses web checklists, forms, lists, or questionnaires. For example, the FAIR Metrics Group's FAIR Compliance Assessment Metrics uses a questionnaire format with one question per indicator, totaling 15 questions (22 items), asking assessors to answer ques-

tions to evaluate a resource’s FAIR compliance. FAIRdat also sets one question per indicator, totaling 10 questions, using a questionnaire format for dataset FAIR compliance assessment. The FAIR Data Assessment Tool sets 11 questions in questionnaire format. The 5-Star Data Assessment Tool sets 14 questions based on its 14 indicators, using a questionnaire format to answer each indicator’s question dimensions.

Assessment results are presented either as a single summary result (e.g., the FAIR Data Assessment Tool uses numbered options from 1 to N representing worst to best, providing a final green bar chart as the assessment result) or as star ratings for the four FAIR dimensions (represented by 1-5 stars). For instance, FAIRdat provides a star rating for each dimension after completing all questions in that dimension (e.g., the “Findable” dimension). The 5-Star Data Assessment Tool provides star ratings for all four FAIR dimensions (1-5 stars) upon completion.

2.2 Maturity-Based Assessment Tools

Maturity-based assessment tools are represented by the Research Data Alliance’s FAIR Data Maturity Model, which has spawned the FAIRsFAIR Data Object Assessment Metrics and the EOSC FAIR Assessment Metrics.

In January 2019, the Research Data Alliance established the FAIR Data Maturity Model Working Group, dedicated to researching FAIR data assessment. After more than a year of work, the group officially released the “FAIR Data Maturity Model Specification and Guidelines” in April 2020. This document proposes a FAIR compliance assessment framework based on maturity models—the FAIR Data Maturity Model—which includes assessment indicators, indicator importance levels, and assessment methods. The model’s indicators are also based on the FAIR principles, comprising 41 indicators (7 for Findable, 12 for Accessible, 12 for Interoperable, and 10 for Reusable) (see Table 2). These indicators are derived from the FAIR principles and divided according to data and metadata. For example, “F1: (Meta)data are assigned a globally unique and persistent identifier” is subdivided into four indicators: RDA-F1-01M, RDA-F1-01D, RDA-F1-02M, and RDA-F1-02D.

Additionally, the FAIR Data Maturity Model distinguishes indicator importance levels based on data providers’ or publishers’ perceptions of each indicator’s importance for FAIR implementation, dividing them into three levels: Very Important, Important, and Useful. “Very Important” indicates that the indicator plays a crucial role in achieving FAIRness in most cases; “Important” means the indicator may not be critical in certain contexts but can significantly enhance FAIRness; “Useful” means the indicator is beneficial but not essential. Among the 41 indicators, 20 are “Very Important,” 14 are “Important,” and 7 are “Useful.”

The FAIRsFAIR Data Object Assessment Metrics (v0.4), released in October 2020, were developed by FAIRsFAIR based on the RDA FAIR Data Maturity

Model. This version includes 17 indicators (see Table 3) for assessing the FAIR compliance of research data objects. The FAIRsFAIR Data Object Assessment Metrics do not adopt all “Very Important” indicators from the FAIR Data Maturity Model; instead, they include some indicators considered merely “Important” in the original model, such as three indicators in the “Interoperable” dimension that were not “Very Important” in the FAIR Data Maturity Model.

The EOSC FAIR Assessment Metrics are also based on the RDA FAIR Data Maturity Model, selecting 26 indicators to form the EOSC FAIR Assessment Metrics for evaluating datasets and other digital objects in the European Open Science Cloud. This model includes 5 Findable indicators (RDA-F1-01D/E, RDA-F1-02D/E, RDA-F2-01M/E, RDA-F3-01M/E, RDA-F4-01M/E), 8 Accessible indicators (RDA-A1-01M/I, RDA-A1-02M/I, RDA-A1-02D/E, RDA-A1-03D/E, RDA-A1-04M/E, RDA-A1-04D/E, RDA-A1-05D/I, RDA-A2-01M/E), 5 Interoperable indicators (RDA-I1-01M/I, RDA-I1-01D/I, RDA-I1-02M/I, RDA-I1-02D/I, RDA-I2-01M/I), and 8 Reusable indicators (RDA-R1-01M/E, RDA-R1.1-01M/E, RDA-R1.1-02M/I, RDA-R1.1-03M/I, RDA-R1.2-01M/I, RDA-R1.3-01M/E, RDA-R1.3-01D/E, RDA-R1.3-02M/E) (see Table 2 for RDA FAIR Data Maturity Model indicator identifiers and importance levels).

Regarding assessment methods, the FAIRsFAIR Data Object Assessment Metrics and EOSC FAIR Assessment Metrics have not proposed explicit assessment methods, while the RDA FAIR Data Maturity Model provides two assessment methods. The first method assesses FAIR progress by evaluating the maturity level of each indicator to determine a digital resource’s FAIR compliance degree for that indicator. Maturity levels include five stages (see Table 4): 0—Not Applicable; 1—Not Yet Considered; 2—Under Consideration/Planning; 3—Being Implemented; 4—Fully Implemented.

Figure 1 [Figure 1: see original paper] visualizes assessment results using this method, clearly showing that the assessed digital resource performs well in “Findable” but still has some indicators needing improvement in “Accessible,” “Interoperable,” and “Reusable.” This method is particularly suitable for data creators or publishers conducting self-assessment to identify areas for FAIRification improvement.

The second method assesses “compliance or non-compliance” for each indicator, requiring only a “compliant” or “non-compliant” answer to evaluate whether a digital resource meets the indicator. For example, when assessing “RDA-F4-01M” (metadata are registered or indexed in a searchable resource), if a digital resource cannot achieve metadata registration or indexing, the result is “non-compliant”; if it can, the result is “compliant.” This method is stricter than the first, as each indicator has only two possible outcomes, effectively counting only those indicators that reach Level 4 in the first method as “compliant.”

In addition to assessing each indicator’s compliance, this method also considers indicator importance levels to evaluate a digital resource’s overall FAIR com-

pliance. By assessing compliance for each indicator and combining importance levels, the compliance level for each FAIR dimension is calculated as shown in Table 5 .

Figure 2 [Figure 2: see original paper] visualizes results using the second method. The assessed resource reaches Level 5 in “Findable,” Level 3 in “Interoperable” (meaning most “Important” indicators and some “Useful” indicators are met), while “Accessible” and “Reusable” have not yet reached the minimum Level 1 requirement. This second method is suitable for third-party organizations (such as funding agencies) to evaluate the FAIRification level of resources they fund.

3. Comparative Analysis of Assessment Models/Tools

3.1 Assessment Method Types

Two types can be distinguished: The FAIR Compliance Assessment Metrics, FAIRdat, FAIR Data Assessment Tool, and 5-Star Data Assessment Tool belong to the same type—self-assessment tools using web checklists, forms, lists, or questionnaires. Each indicator includes several questions with various response options, generating assessment results through question responses. Results are presented either as a summary outcome (e.g., the FAIR Data Assessment Tool) or as star ratings for the four FAIR dimensions (e.g., FAIRdat, 5-Star Data Assessment Tool).

The FAIR Data Maturity Model, FAIRsFAIR Data Object Assessment Metrics, and EOSC FAIR Assessment Metrics belong to another type. Although the latter two have not proposed explicit assessment methods, their indicators are derived from the FAIR Data Maturity Model and may consider maturity assessment methods in the future. The FAIR Data Maturity Model, based on maturity model theory and methods, assesses dataset FAIRification levels and identifies areas for improvement. Unlike checklist-based tools that focus only on final results, it provides maturity levels for each indicator (typically five levels). Assessment results not only provide a final maturity evaluation but also reveal gaps from the highest maturity level, allowing assessors to progressively improve and ultimately achieve optimal FAIRification.

3.2 Automation Level of Assessment Methods

Most assessment models/tools rely primarily on manual evaluation, typically using self-assessment by dataset owners. Currently, the FAIR Metrics Group and FAIRsFAIR are exploring automated assessment, but this remains under research. While manual evaluation is understandable, especially given the subjective nature of some FAIR principles (e.g., richness of data description) that require human judgment, assessing large-scale digital objects solely through manual evaluation is unrealistic. More automated evaluation modes are needed, using machines or automated programs to determine digital resources’ FAIR compliance. However, due to varying standards and requirements across disciplines, lack of machine-readable resources, insufficient metadata richness, and

other issues, implementing automated evaluation remains challenging, and no fully automated assessment tool currently exists.

3.3 Operability of Assessment Methods

The FAIR Data Maturity Model is the most comprehensive in terms of operability, offering two assessment methods with strong practicality. The FAIR Data Assessment Tool, FAIRdat, and 5-Star Data Assessment Tool primarily use web checklists, forms, lists, or questionnaires, with relatively simple processes. The FAIRsFAIR Data Object Assessment Metrics and EOSC FAIR Assessment Metrics have not yet provided specific assessment methods.

3.4 Indicator Quantity and Distribution

Except for the 5-Star Data Assessment Tool, the other six tools base their indicators on the FAIR principles. The FAIR Data Maturity Model has the most indicators (41), while FAIRdat has the fewest (10). The distribution of indicators across the four FAIR dimensions varies among tools. The FAIR Compliance Assessment Metrics, FAIRdat, and FAIR Data Assessment Tool tend to focus more on “Findable” and “Accessible” dimensions, with fewer indicators for “Interoperable” and “Reusable.” In contrast, the FAIR Data Maturity Model and 5-Star Data Assessment Tool emphasize “Interoperable” and “Reusable” dimensions more heavily. The EOSC FAIR Assessment Metrics focus more on “Findable” and “Reusable,” while the FAIRsFAIR Data Object Assessment Metrics distribute indicators relatively evenly across all four dimensions (see Table 6).

3.5 Metadata Indicator Settings

Rich, machine-actionable metadata is essential for data and service discoverability, making metadata a critical component of the FAIR principles. The FAIR Compliance Assessment Metrics, FAIRdat, FAIR Data Assessment Tool, and 5-Star Data Assessment Tool do not explicitly distinguish between data and metadata level indicators. In contrast, models that clearly differentiate between data and metadata—namely the FAIR Data Maturity Model, FAIRsFAIR Data Object Assessment Metrics, and EOSC FAIR Assessment Metrics—emphasize metadata indicators. For example, among the FAIR Data Maturity Model’s 41 indicators, 23 concern metadata; among the FAIRsFAIR Data Object Assessment Metrics’ 17 indicators, 13 concern metadata; and among the EOSC FAIR Assessment Metrics’ 26 indicators, 16 concern metadata.

3.6 Indicator Clarity

Indicators related to “Findable,” “Accessible,” and “Interoperable” are generally clear and easy to understand across the seven assessment models/tools. However, indicators for “Reusable” are either too few (e.g., only one indicator in the FAIR Data Assessment Tool) or too numerous (e.g., the FAIR Data Maturity

Model has three indicators just for “metadata license agreement”: “metadata includes data reuse license information,” “metadata points to a standardized reuse license,” and “metadata points to a machine-understandable reuse license”). Indicators in the “Reusable” dimension also suffer from ambiguity and insufficient differentiation. For example, in the FAIRsFAIR Data Object Assessment Metrics, the “Reusable” indicators “metadata about data content,” “domain metadata standardization,” and “data file format” are not clearly distinguishable. Similarly, the EOSC FAIR Assessment Metrics’ “Reusable” indicators “metadata conforms to domain standards” and “metadata is represented in a machine-understandable domain standard” lack clear differentiation. Therefore, indicator clarity in the “Reusable” dimension needs improvement.

4. Overall Evaluation of FAIR Data Assessment Models and Tools

The seven assessment models/tools primarily evaluate datasets. Non-data digital objects such as software and semantics have not yet been evaluated, mainly because the FAIR principles are primarily data-focused guidelines, and assessment models/tools based on these principles naturally focus on datasets as the primary assessment objects. The models/tools generally do not limit their application domains, making them usable by various stakeholders (data creators, data publishers, research funding agencies, etc.) (see Table 7).

Each assessment model/tool has its strengths and weaknesses. Self-assessment tools like the FAIR Compliance Assessment Metrics, FAIRdat, FAIR Data Assessment Tool, and 5-Star Data Assessment Tool offer simple assessment processes but are labor-intensive and time-consuming, requiring deep familiarity with the dataset. Their assessment result calculations are also highly subjective, with none of these tools detailing their calculation methods. The FAIRsFAIR Data Object Assessment Metrics integrates selected indicators from the FAIR Data Maturity Model, making it more concise—for example, including only three indicators in the “Interoperable” dimension. It also uses different expressions in some cases, such as using “descriptive core metadata” instead of “metadata richness” in the FAIR Data Maturity Model. However, its limitation is that it provides only an indicator framework without specific evaluation methods.

Distinguishing indicator importance levels is a key feature of the FAIR Data Maturity Model. Data creators or publishers can focus on assessing, improving, and enhancing the 20 “Very Important” indicators. The model also provides two assessment methods for evaluating either individual indicators (Method One) or FAIR dimensions (Method Two), offering a unique perspective on maturity levels. The EOSC FAIR Assessment Metrics selects indicators from the FAIR Data Maturity Model but, unfortunately, also fails to provide specific evaluation methods.

5. Recommendations for Selecting and Applying FAIR Data Assessment Models and Tools

The seven assessment models/tools each have distinct functional characteristics, different indicators, and assessment methods, making them complementary. Therefore, when selecting and applying FAIR compliance assessment models/tools, domestic organizations should draw on the strengths and features of each model rather than adopting an either/or approach. Considering factors such as assessment method type, operability, and indicator quantity and distribution, this paper proposes a reference solution: **FAIRsFAIR Data Object Assessment Metrics + RDA FAIR Data Maturity Model**.

Assessment indicators and methods are key considerations when selecting and applying FAIR compliance assessment models/tools. The FAIRsFAIR Data Object Assessment Metrics includes 17 indicators distributed relatively evenly across the four FAIR dimensions, largely consistent with the FAIR principles. It integrates selected indicators from the FAIR Data Maturity Model, making it more concise while inheriting the feature of distinguishing indicator importance levels. Therefore, its indicators represent a reliable choice. However, the FAIRsFAIR Data Object Assessment Metrics may not be entirely suitable for all organizations. Domestic organizations should consider indicator inclusiveness—such as whether they meet the needs of multiple stakeholders and different disciplinary domains—and modify and fine-tune indicators based on their own assessment purposes and requirements to establish more scientific and reasonable assessment indicators.

Regarding assessment method selection, since the FAIRsFAIR Data Object Assessment Metrics has not yet proposed explicit assessment methods, the FAIR Data Maturity Model's assessment methods can be adopted. Unlike self-assessment tools using web checklists/forms/lists or questionnaires that focus only on a final assessment result, the FAIR Data Maturity Model, based on maturity model theory and methods, provides maturity levels for each indicator to assess dataset FAIRification levels and identify areas for improvement. The five development levels it defines represent a standard process that data FAIRification must undergo. When all data repositories advance their data FAIRification according to these five levels, standardized FAIR implementation will be within reach. Furthermore, when all data resources use this assessment method, it becomes a benchmark for measurement, facilitating comparison of FAIRification levels across different data repositories.

It should be noted that the maturity model-based assessment method in this solution is still essentially manual evaluation. Future development should move toward automated assessment as needs and technologies evolve. Large-scale data production is a hallmark of data-intensive research, and when FAIR data is large-scale and machine-understandable, FAIR assessment must also adopt automated methods to keep pace. For this reason, FAIRsFAIR has developed an automated assessment tool called F-UJI based on 16 of the 17 indicators in the

FAIRsFAIR Data Object Assessment Metrics. F-UJI evaluates data resources based on data object identifiers (such as PIDs or URLs) and has been tested on datasets from five CoreTrustSeal-certified repositories, with plans to continuously expand collaborative testing to additional repositories. Therefore, both assessment indicators and methods are not static; as needs and technologies change, more diverse models can be selected.

This paper has analyzed seven FAIR compliance assessment models and tools, demonstrating international organizations' efforts to establish clear, discriminative, measurable, and universally applicable FAIR compliance assessment indicators. It should be emphasized that assessment is not an end in itself; more importantly, effective measures and actions should be taken based on assessment results to address identified issues and ultimately improve data FAIRness.

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