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SOFTWARE TOOL ARTICLE

REVISED Digital Passport Model Assessment Workbench: SHACL-based assessment, use-case coverage, and integration guidance for digital passport model ecosystems

[version 2; peer review: 1 approved, 1 approved with reservations, 2 not approved]

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Abstract

Digital Product Passports and Digital Material Passports are increasingly implemented through modular data model ecosystems that evolve across releases and interact with external sectoral models. This creates a practical model evaluation problem: model developers need reproducible evidence about model structure, constraint readiness, interoperability, use-case coverage, and integration risks before representative instance datasets are available. We present the Digital Passport Model Assessment Workbench (DP-AWB), an open-source software tool that computes deterministic assessment results directly from Shapes Constraint Language (SHACL) model specifications, where SHACL is used to describe the expected structure, fields, and constraints of linked data models. DP-AWB provides metrics for structural scale, typed and cardinality-bounded properties, constraint density, object references, cross-module references, maintainability findings, lexical-structural use-case coverage evidence, comparison signals, prioritised improvement targets, and composition recommendations. Coverage evidence is not a semantic-equivalence determination. The tool is distributed as the Python package dpawb on PyPI and as a containerised Model Context Protocol server registered as io.github. CE-RISE-software/dpawb. We demonstrate the workflow on a battery Digital Product Passport application by comparing the CE-RISE Digital Passport model ecosystem with the BatteryPass v1.2.0 model ecosystem represented through inferred SHACL proxies. The demonstration shows that CE-RISE provides broader Digital Passport infrastructure and lifecycle coverage, while BatteryPass provides compact battery-sector content. A reviewed alignment retained 14 strict overlap pairs, all present on

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both sides, and DP-AWB recommended a combined 19-module composition with explicit deduplication review items. The workbench therefore supports transparent model assessment, use-case-driven prioritisation, and integration planning for evolving digital passport ecosystems.

Plain Language summary
Digital passports are digital records that describe products and materials so that they can be reused, repaired, recycled, or assessed more effectively. The data models behind these passports can become large and difficult to inspect manually. DP-AWB is a software tool that reads SHACL model files and produces reproducible evidence about how large, explicit, connected, and usable a model is. It can also compare two model ecosystems and highlight where they overlap or where a use case is not yet well supported. In this article we describe the tool and demonstrate it by comparing CE-RISE Digital Passport models with BatteryPass models for a battery passport application. The example shows how the tool helps identify complementary strengths and produces integration guidance rather than only a simple score.

Keywords
Digital Product Passport, Digital Material Passport, SHACL, model assessment, interoperability, use-case coverage, Model Context Protocol, CE-RISE, BatteryPass, software tool

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REVISED **Amendments from Version 1**

This version addresses the peer-review comments. We added relevant literature and clarified that DP-AWB uses lexical-structural matching, not semantic reasoning or operational DPP evaluation. We documented the BatteryPass-to-SHACL proxy conversion, metric and decision rules, the interpretation of indeterminate findings, and the limits of the demonstration. The conclusion now describes the results as design-time decision evidence.

Any further responses from the reviewers can be found at the end of the article

1. Introduction

Digital Product Passports (DPPs) and Digital Material Passports are becoming a central mechanism for making product-level information reusable across circular economy value chains. In the CE-RISE project, the passport is part of a broader Resource Information System that connects product data with reuse, repair, refurbishment, recycling, product environmental footprint, and socio-economic and environmental assessment needs.[1,2] Such systems require not only individual schemas but modular model ecosystems that can evolve, interoperate, and be compared with sector-specific initiatives.

This creates a model evaluation and selection problem. Traditional data validation asks whether an instance dataset conforms to a model. In early and evolving DPP contexts, representative datasets may not yet exist, while model authors and adopters already need to decide which model components are fit for an application, whether changes across releases improve or weaken the model, whether external models cover equivalent information, and which gaps matter for a use case. Manual inspection is insufficient for model suites with thousands of shapes and properties, frequent revisions, and multiple downstream reuse scenarios.

Digital Product Passport research contains related but distinct strands. Ecosystem and architecture work frames the passport as a socio-technical system spanning actors, lifecycle stages, information governance, and technical interoperability.[3] Other work develops cross-sectoral DPP ontology networks and SHACL shapes for data quality and validation,[4] while DPP-system requirements research addresses the operational infrastructure needed to collect, govern, and exchange lifecycle data.[5] These contributions motivate interoperable formal models and operational DPP systems, but they have different objectives from assessing alternative model specifications before representative data are available.

SHACL itself is a W3C language for validating a data graph against a shapes graph.[6] Ontology-quality assessment and schema/ontology matching research likewise provide established methods for evaluating knowledge models or inferring correspondences.[7–9] DP-AWB is complementary to these approaches: it does not propose another DPP schema, infer semantic equivalence, or execute conformance checking over instance data. Instead, it analyses the structure and declared constraints of shape graphs, applies a deliberately limited lexical-structural coverage procedure, and produces reproducible comparison and integration-review evidence. To our knowledge, this combination of shape-graph assessment, use-case coverage evidence, reviewed alignments, and composition guidance has not previously been provided for DPP model ecosystems.

DP-AWB addresses this problem as a SHACL-based model assessment workbench. The tool reads SHACL specifications directly and computes reproducible assessment, coverage, comparison, prioritisation, and integration recommendation results. The contribution of this article is the software tool and its workflow. The battery DPP comparison is used as a demonstration case showing how the workbench supports evidence-based model evaluation and integration planning.

2. Software description

2.1 Purpose

DP-AWB is designed to turn model specifications into decision evidence. Its central assumption is that SHACL model files contain enough formal structure to support an initial model-level assessment before instance-data validation is possible. The workbench does not replace domain judgement. Instead, it makes structural and coverage evidence explicit, reproducible, and reviewable.

2.2 Distribution and access routes

The tool is distributed through two deployment routes.

- **Python package.** The package `dpawb` is published on PyPI at https://pypi.org/project/dpawb/. At the time of drafting, the verified PyPI metadata reports version 0.1.2, license EUPL-1.2, Python requirement $\geq$ 3.12, and the summary "SHACL-based analytical workbench for digital passport model assessment and use-case coverage".[10]

- **MCP server.** The workbench is also distributed as a containerised Model Context Protocol (MCP) server. The Official MCP Registry entry is `io.github. CE-RISE-software/dpawb`; version 0.1.2 is marked as latest and uses the OCI package `ghcr.io/ce-rise-software/dpawb-mcp:0.1.2` with stdio transport.[11,12]

The MCP route exposes deterministic tools for assessment, coverage, comparison, prioritisation, composition recommendation, schema/template discovery, controlled vocabulary discovery, and summarisation. In the replication workflow used for this article, DP-AWB was accessed through its MCP server only.

2.3 Core workflow

The workbench operates on file-based inputs and emits file-based JSON results. The main input artefacts are:

- a *composition profile*, listing one or more SHACL model sources that together define a model ecosystem;
- an optional *use-case file*, defining required information items and required concept-to-concept joins;
- an optional *alignment file*, defining analyst-reviewed equivalences between model entities before deduplication.

Figure 1 summarises DP-AWB as an instrument panel. The five evidence perspectives organise low-level SHACL metrics and diagnostic findings into model-evaluation signals, while the output layer exposes the corresponding decision artefacts.

Table 1 lists the principal MCP tools used to produce the deterministic result documents.

Every operation emits a persisted JSON result document with result_type, inputs, content, and diagnostics fields. For example, a coverage result records an overall coverage class plus one finding per required item and join; each finding includes its coverage class, explanatory adequacy note, and supporting SHACL trace (matched paths, owner shapes, target classes, and reference targets). The complete machine-readable results used in this article are deposited with the replication package,[17] so readers can inspect both the output values and the evidence used to derive them.

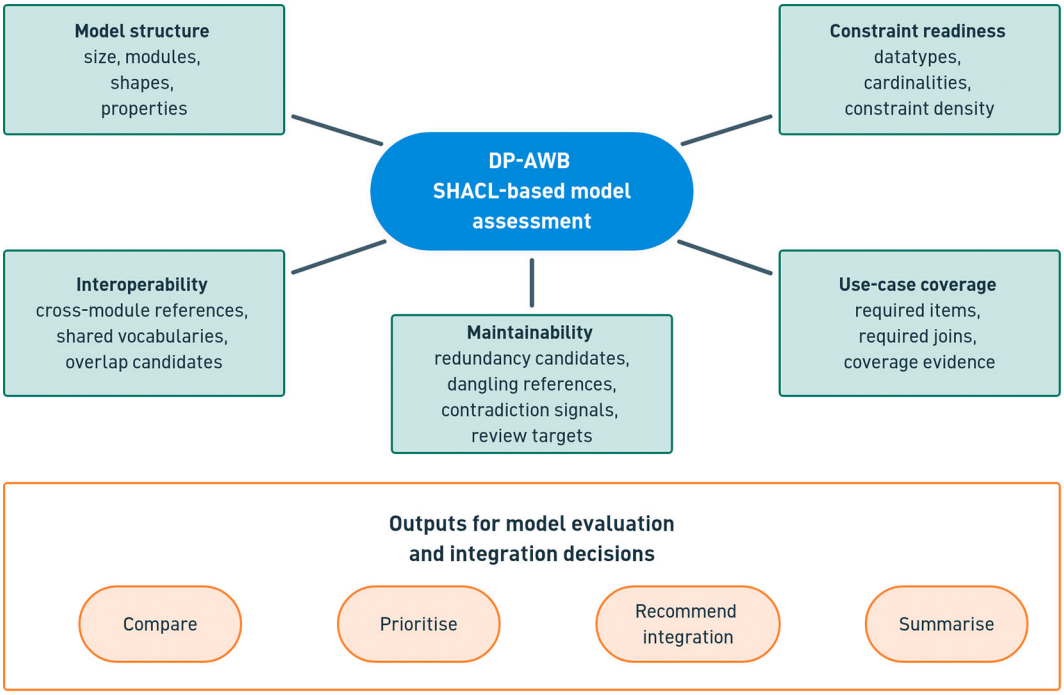


Figure 1. DP-AWB instrument panel.

Table 1. Principal DP-AWB MCP tools used in the reproducible assessment workflow.

Tool	Role
`assess`	Computes structural, explicitness, interoperability, and maintainability metrics for one composition profile.
`coverage`	Assesses the evidence that one composition profile covers the required items and joins of a use case.
`compare`	Compares two assessment results, optionally applying an analyst-authored alignment file.
`prioritize`	Ranks improvement targets from assessment, comparison, and coverage evidence.
`recommend_composition`	Recommends a deterministic candidate composition from two assessed ecosystems and optional downstream evidence.
`summarize`	Creates a deterministic summary result from existing result documents.

3. Assessment method

3.1 Assessment perspectives

DP-AWB computes an instrument panel of complementary evidence categories. The current workflow emphasises five perspectives:

1. **Model structure:** number of modules, node shapes, property shapes, object-reference properties, and structural scale.

2. **Constraint readiness:** shares of typed and cardinality-bounded properties, constraint density, and related explicitness indicators.

3. **Interoperability:** cross-module references, shared vocabulary overlap, and declared or candidate overlaps between model ecosystems.

4. **Maintainability:** deterministic findings such as dangling references, contradictions, and redundancy candidates.

5. **Use-case coverage:** evidence for required information items and required joins.

3.1.1 Core metric and rule definitions

For reproducibility, let P be the set of property shapes in the composed profile and C the number of SHACL constraint statements attached to them, counted over the workbench released constraint-predicate set. Constraint density is C/|P| (defined as 0 when |P|= 0). It is therefore a count of declared constraints per property shape, not a measure of model quality or regulatory compliance.

For a module m, let V_m be the set of URI IRIs occurring as a subject, predicate, or object in its RDF triples. With U = union(V_m) and R = {v in U: v occurs in more than one V_m}, the shared-vocabulary ratio is |R|/|U| (defined as 0 when U is empty). It measures literal IRI reuse across the supplied modules; it is not label similarity or evidence of semantic equivalence.

Redundancy candidates are calculated within, not across, modules. A candidate group is emitted only when two or more property shapes share the same non-empty six-element signature: (sh:path, sh:datatype, sh:class, sh:node, sh:minCount, sh:maxCount). It is a conservative inspection signal, rather than a determination that the repeated shapes are modelling errors.

3.2 Coverage model

Use-case coverage is intentionally SHACL-only. A use case is formalised as a set of required information items and joins. An information item is a piece of information needed by the application, such as a battery identifier or carbon-footprint value. A join describes an expected connection between such items, for example that product identification should be connectable to material composition or carbon-footprint evidence. The workbench checks what evidence the assessed

SHACL sources provide for these requirements. *Indeterminate*, for example, can mean that the model contains related evidence but that the deterministic SHACL evidence is not specific enough for a direct match.

Coverage matching is a deterministic lexical-structural procedure, not semantic matching. For each required item, DP-AWB normalises and tokenises its identifier and label, then compares those tokens with the IRIs, labels, property paths, owner shapes, and target classes declared in SHACL. It splits compound identifiers (for example camelCase) and applies a small, explicit set of lexical variant groups, including identifier/id, category/classification, and manufacturer/operator/producer/actor. A direct item match requires every core required token, including an approved lexical variant, to be found; lower token overlap, or a match with weak structural support, yields partial or indeterminate evidence.

The procedure does not perform ontology reasoning, embedding or LLM-based similarity, external-vocabulary lookup, or general semantic-equivalence determination. A required join is direct only when the matched items occur in a shared owner shape or have an explicit object-reference path; otherwise it remains partial or indeterminate. The resulting coverage classes are deliberately conservative evidence classes rather than claims that concepts are semantically equivalent or that a model can represent all instance-level data. Declared equivalences used for deduplication remain analyst-authored and are reviewed separately (Section 3.3).

3.3 Alignment and integration

The comparison workflow can apply analyst-authored equivalence files. This is important because similarity between model labels is not sufficient for deduplication. The alignment file records only equivalences that the analyst is willing to use as explicit overlap evidence. DP-AWB then checks whether the declared left and right entities are present in the corresponding assessment traces and uses the resulting comparison evidence in prioritisation and composition recommendation.

3.4 Decision rules and boundary of recommendations

The comparison operation first requires the same declared comparison scope on both inputs. It computes a delta for each shared structural metric and orders non-zero observations by a fixed signal priority and normalized absolute delta; it does not calculate an overall quality score or select a universally better model. When an alignment file is supplied, the operation only checks whether each analyst-declared pair is present on the left and right traces. The reported alignment coverage ratio is therefore bilateral declared-pair presence divided by the number of declared pairs, not an estimate of alignment recall or completeness.

Prioritisation is a deterministic follow-up queue with no learned model, hidden weights, or expert-derived numerical scoring. The current fixed rank bases are: not-representable coverage findings (1); partial or indeterminate coverage findings (2); contradictions or dangling references (3); unmatched declared alignment pairs (4); selected structural comparison signals (5); and redundancy candidates (6). Each result includes a rule trace explaining the trigger and the final list is ordered by that fixed basis and target identifier. The reported priority rank is the ordinal position after sorting by (fixed rank basis, target identifier); it is not a composite weighted score.

Composition recommendation is deliberately not an automatic merge or a validated deployment solution. It emits a candidate profile that retains the modules of both declared input profiles, then adds deduplication review items only for analyst-declared equivalence pairs. Coverage evidence determines a preferred side for such a pair, but DP-AWB does not generate transformation rules, canonical concepts, conflict-resolution rules, or executable mappings. Those implementation decisions require domain and system-integration review outside the current model-assessment scope. For each profile, coverage findings receive fixed values of 0 (not representable), 1 (indeterminate), 2 (partially representable), or 3 (representable); their sum divided by three times the number of findings is used only to choose the preferred side of an analyst-declared duplicate. Every input module is retained in the candidate profile.

4. Operation

4.1 Minimal package route

The Python package route is intended for local or scripted use:

```
python -m pip install dpawb
```

The package documentation and source repository are linked from the PyPI metadata and listed in the Software availability section.[13,14]

4.2 Containerised MCP route

The MCP route is intended for use by MCP-capable clients and agentic workflows. The registry-supported package is the OCI image:

```
ghcr.io/ce-rise-software/dpawb-mcp:0.1.2
```

In a local workspace, a stdio server can be launched with a mounted working directory, for example:

```
podman run --rm -i \
    -v /path/to/workspace:/workspace:Z \
    -w /workspace \
    ghcr.io/ce-rise-software/dpawb-mcp:0.1.2
```

This route was used to produce the persisted JSON results in the demonstration.

Figure 2 presents the operational workflow used in the demonstration. The same pattern can be applied to release monitoring, comparison of model alternatives, and documentation of integration decisions.

5. Use case: battery DPP model integration

5.1 Purpose of the demonstration

The demonstration evaluates the workbench from the viewpoint of a battery Digital Product Passport application. The goal is not to declare a single model ecosystem superior, but to show how DP-AWB can reveal structural differences, use-case evidence, strict overlaps, and integration guidance.

The battery use case is an author-defined analytical demonstration, not a claim to be an exhaustive regulatory checklist or an industrially validated requirements specification. Its required items and joins deliberately span identity, composition, performance, environmental, compliance, lifecycle, and circularity domains so that the tool can be exercised across the declared model scope. The versioned use-case file and application-scope note in the replication package make those choices inspectable and replaceable for another sector, regulation, or stakeholder-validated application.

5.2 Compared ecosystems

The left ecosystem is the CE-RISE Digital Passport model ecosystem. For this demonstration, the assessed profile uses a version-pinned CE-RISE generated SHACL release set, covering 12 modules: passport metadata, access and governance, custody, product profile, material profile, traceability and life-cycle events, usage and maintenance, diagnostic results, integrated life-cycle assessment, circularity and end of life, compliance and standards, and RE indicators. The profile version is recorded as `ce-rise-versioned-shacl-release-set`. Table 2 records the corresponding CE-RISE

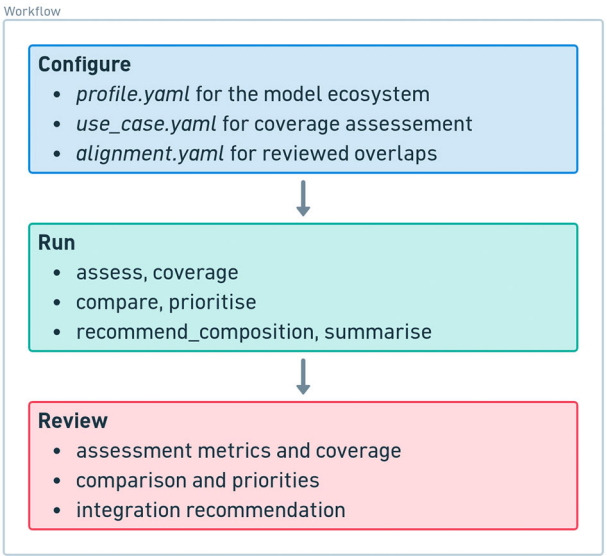


Figure 2. Reproducible DP-AWB workflow.

Table 2. CE-RISE modules included in the full battery DPP assessment profile.

Assessment module	Repository	Version
dp_record_metadata	dp-record-metadata	v0.0.2
dp_access_and_governance	dp-access-and-governance	v0.0.3
dp_record_custody	dp-record-custody	v0.0.3
product_profile	product-profile	v0.0.3
material_profile	material-profile	v0.0.1
traceability_and_life_cycle_events	traceability-and-life-cycle-events	v0.0.3
usage_and_maintenance	usage-and-maintenance	v0.0.2
diagnostic_results	diagnostic-results	v0.0.3
integrated_lca	integrated-lca	v0.0.3
circularity_and_eol	circularity-and-eol	v0.0.3
compliance_and_standards	compliance-and-standards	v0.0.3
re_indicators_specification	re-indicators-specification	v0.0.5

model repository and model version tag used for the assessment.[15] This mirrors the treatment of BatteryPass as a specific assessed release, v1.2.0, rather than as an unversioned live source.

The CE-RISE sources are therefore not treated as an abstract live endpoint in this assessment. The demonstration records the concrete model version used for each module, while the archived composition profile provides the exact SHACL source URLs used to rerun DP-AWB.

The right ecosystem is the BatteryPass v1.2.0 data model ecosystem.[16] BatteryPass is distributed as SAMM/RDF Turtle model sources rather than official SHACL shapes. For this assessment, the seven selected v1.2.0 Turtle modules were converted into inferred SHACL proxy files so that both ecosystems could be assessed through the same SHACL-based workflow. This proxy status is a methodological limitation and is reported explicitly.

The conversion is deterministic and is included, together with the copied source files and generated proxies, in the replication archive.[17] It maps each SAMM Aspect and Entity to a SHACL NodeShape while retaining the original IRI; SAMM properties become SHACL property links with the original property IRI as sh:path. A SAMM optional flag becomes sh:minCount 0, otherwise sh:minCount 1 is asserted, and non-list characteristics receive sh:maxCount 1. Characteristics are resolved to XSD datatype or class/node constraints; list element characteristics, enumerations, regular-expression constraints, range bounds, inheritance, labels, descriptions, examples, units, and source links are retained or mapped to corresponding SHACL constraints or trace annotations.

The proxies therefore preserve the available source structure and constraint information but are not official BatteryPass SHACL publications. In particular, inferred cardinalities and the SHACL rendering of SAMM constructs can affect shape-level metrics. We consequently interpret the BatteryPass values as a transparent, reproducible proxy assessment, not as an assertion about an official BatteryPass SHACL release; the archived converter can be rerun or reviewed as the source model evolves.[17]

5.3 Structural assessment results

Table 3 summarises the structural assessment results emitted by the DP-AWB `assess` tool for the two composition profiles. The metrics are model-level signals, not validation results over passport instance data.

Table 3. Structural assessment snapshot for the battery DPP demonstration.

Profile	Modules	Node shapes	Property shapes	Typed share	Bounded share
CE-RISE full battery DPP	12	1515	4321	0.984	0.862
BatteryPass proxy	7	41	154	1.000	1.000

The terms used in the table have the following meaning. A *module* is one SHACL model source included in the assessed profile. A *node shape* is a SHACL definition of the constraints that apply to an entity or class of objects, for example a product, material, diagnostic result, or lifecycle event. A *property shape* is a SHACL constraint on one field or relationship of such an entity. The *typed property share* is the fraction of property shapes that explicitly constrain the kind of value expected, for example through a datatype, class, node shape, or node-kind constraint. The *cardinality-bounded property share* is the fraction of property shapes with explicit occurrence constraints, such as minimum or maximum counts. Both shares range from 0 to 1. Higher values mean that more properties are explicit in the SHACL model; they do not by themselves mean that a model is better or more complete for a specific application.

The CE-RISE ecosystem is much broader structurally, with 12 modules, 1515 node shapes, and 4321 property shapes. This reflects its role as a wider DPP model ecosystem covering passport infrastructure, lifecycle information, diagnostics, LCA, compliance, circularity, and RE indicators. The BatteryPass proxy is smaller, with 7 modules, 41 node shapes, and 154 property shapes, which is consistent with a focused battery-sector content model. The typed property shares are high in both profiles, meaning that most constrained fields and relationships carry explicit value-type information. The cardinality-bounded share is complete in the BatteryPass proxy and high, but lower, in CE-RISE. This indicates that the BatteryPass proxy is more uniformly bounded in the inferred SHACL representation, while CE-RISE leaves some properties more open across a broader model ecosystem. The difference is therefore interpreted as evidence of different modelling roles, not as a quality ranking.

5.4 Interoperability and maintainability results

Table 4 reports the assessment signals corresponding to the interoperability and maintainability perspectives. Interoperability is represented here by object-reference properties, cross-module references, and shared-vocabulary overlap. An object-reference property is a model field that points to another structured object rather than to a simple value such as text or a number. Shared-vocabulary overlap counts terms that appear to be reused or shared across the compared model evidence. Maintainability is represented by deterministic findings emitted by DP-AWB, in this case redundancy candidates.

The interoperability signals show different modelling architectures. CE-RISE has many more object-reference properties because it is a larger modular ecosystem, and it contains a small number of explicit cross-module references. BatteryPass has fewer object-reference properties and no cross-module references in the inferred proxy, which is consistent with a more compact sector model. Its shared-vocabulary ratio is higher because a smaller vocabulary contains a larger relative share of terms overlapping with the comparison evidence. The maintainability findings are redundancy candidates rather than validation errors. Their much larger number in CE-RISE mainly reflects the larger model surface and repeated constraint patterns across modules; they identify review targets, not defects by themselves.

5.5 Coverage results

Table 5 reports the coverage classification counts. The battery DPP use case combines 81 required-item and required-join findings. Table 5 reports the resulting lexical-structural coverage evidence. “Direct” means that the deterministic procedure found the required token evidence and, where applicable, adequate structural support; it is not a semantic coverage score.

Table 4. Interoperability and maintainability signals from the structural assessment.

Profile	Object refs	Cross-module refs	Shared vocab items	Shared vocab ratio	Findings
CE-RISE full battery DPP	656	6	60	0.020	132
BatteryPass proxy	37	0	43	0.082	2

Table 5. Lexical-structural coverage evidence for the full battery DPP use case.

Profile	Direct	Partial	Indeterminate	No direct
CE-RISE full battery DPP	17	19	45	0
BatteryPass proxy	29	14	28	10

BatteryPass has stronger direct lexical-structural evidence for core battery passport content, including product identity, battery category, carbon footprint, material composition, circularity, performance and durability, and labelling. CE-RISE has broader evidence for passport governance, custody, traceability, lifecycle events, usage and maintenance, diagnostics, integrated LCA, compliance, circularity and end-of-life information, and RE indicators. BatteryPass has explicit gaps for broader application capabilities such as calculation evidence, diagnostic results, maintenance information, responsible sourcing assurance, and usage history. These comparisons show differing model roles; they are not a semantic quality ranking.

The 45 indeterminate CE-RISE findings require further interpretation. Eleven are item-level findings for battery chemistry, calculation evidence, carbon-footprint concepts, compliance declarations, dismantling information, hazardous substances, manufacturing place, responsible-sourcing assurance, and performance concepts. In each case the model contains only partial lexical evidence under the deliberately narrow matching procedure. The finding does not mean that the information is absent; it identifies a candidate for a battery-specific mapping, a more precise use-case requirement, or a human semantic review.

The remaining 34 indeterminate findings are joins. Several have matched endpoint items but no shared owner shape or explicit object-reference path, while others inherit indeterminacy from one endpoint. This can reflect intentionally layered modules, an undeclared cross-module relationship, or a terminology mismatch; it is not evidence that the connection cannot be implemented. Accordingly, indeterminate results are a review queue, not failures. The appropriate next step is to inspect the persisted traces, add an explicit SHACL relationship or a narrowly documented analyst alignment where justified, and then rerun the assessment rather than recoding the result as a semantic match.

5.6 Alignment and integration results

The alignment step connects the comparison to an integration decision. Structural and coverage metrics show how the two ecosystems differ, but they do not by themselves say which concepts should be treated as the same when the models are combined. For that purpose, DP-AWB accepts an analyst-authored alignment file: a human-reviewed list of candidate equivalences between model entities found on the two sides. Here, an *entity* means a SHACL node shape or property shape, such as a product identifier property, a material-composition shape, or an end-of-life-information shape; it does not mean a whole model module such as `product-profile`.

In this demonstration, an *overlap pair* means one CE-RISE entity and one BatteryPass proxy entity that may represent the same application concept. A *strict application-level overlap* means that the pair was judged equivalent for the battery DPP use case, not merely related by topic or wording.

The workflow was therefore: first compile a bounded seed alignment from the assessed model evidence, then review it manually for semantic strictness, then rerun the DP-AWB comparison with the reviewed alignment. The seed alignment is not an exhaustive claim that no other overlaps exist; it is the set of candidate equivalences selected for this demonstration and can be extended in later review cycles. The seed alignment contained 18 candidate equivalences. Review retained 14 strict overlap pairs and excluded four weaker pairs: a related-passport identifier, two spare-parts information pairs, and a broad compliance-statement pair. DP-AWB then checked whether the 14 retained pairs were actually present in the assessed traces on both sides. All 14 were present, giving an alignment coverage ratio of 1.0 for the reviewed alignment. This ratio measures coverage of the declared reviewed alignment, not recall over all possible CE-RISE–BatteryPass overlaps.

DP-AWB then used the reviewed alignment to produce a composition recommendation. In this context, a composition recommendation is not an automatic merge of the models. It is a proposed combined profile plus review items that make duplicate or overlapping entities explicit before implementation. The recommended candidate composition retained 19 modules: all 12 CE-RISE modules and all 7 BatteryPass proxy modules. DP-AWB emitted 14 entity recommendations and 14 deduplication review items, with BatteryPass preferred for reviewed sector-specific duplicates. A deduplication review item is a signal that two aligned entities should not be implemented twice without an explicit modelling decision. The interpretation is a layered composition: CE-RISE remains the broader DPP application and infrastructure layer, while BatteryPass is reused for reviewed battery-sector content overlaps.

6. Discussion

The demonstration shows that DP-AWB is useful when the goal is not to promote one model ecosystem over another, but to make their roles, overlaps, and gaps explicit. The CE-RISE and BatteryPass ecosystems are complementary rather than simply competing. A score-only comparison would obscure this. DP-AWB instead exposes structural scale, explicitness, coverage classes, analyst-reviewed semantic overlap candidates, prioritised gaps, and integration candidates.

For CE-RISE development, the assessment points to areas where battery-specific mappings or constraints should be clarified, especially around battery chemistry, carbon-footprint concepts, calculation evidence, compliance declarations, dismantling information, and hazardous-substance information. For BatteryPass reuse, the assessment supports its role as a compact sector-specific content layer while making explicit that broader lifecycle, diagnostic, maintenance, and governance functions require additional model support.

DP-AWB supports application scoping by making required coverage, indeterminate evidence, redundancy candidates, and duplicate integration candidates explicit. These signals help analysts decide which parts of a broader model ecosystem should be retained, reviewed, or left out of an application-specific composition. This is preferable to requiring users to enumerate excluded information in advance, because in large model ecosystems such exclusions would be difficult to define reliably before the assessment evidence is available.

The interoperability signals in this article are intentionally bounded. Shared vocabulary, object references, and cross-module references are syntactic and structural indicators in the assessed shape graphs. They do not establish semantic interoperability, which requires justified concept mappings and agreement on units, lifecycle boundaries, and regulatory interpretation; nor do they establish operational interoperability, which requires runtime mechanisms for identity, access control, provenance, synchronization, and data exchange. DP-AWB can provide design-time evidence for those later activities, but it does not evaluate or implement them.

The main limitation is that this assessment is SHACL-only and model-level. It does not validate real instance datasets. A second limitation is that use-case coverage is a conservative lexical-structural procedure: it does not establish semantic equivalence, so terminology differences and implicit relationships can yield indeterminate results. A third limitation is the inferred SHACL proxy used for BatteryPass, which is necessary for a common SHACL assessment but is not an official BatteryPass SHACL publication and includes documented conversion assumptions. A fourth limitation is the snapshot character of the demonstration: it compares the selected CE-RISE module versions available at assessment time with BatteryPass v1.2.0, so it should be interpreted as a reproducible assessment snapshot rather than a permanent comparison of the ecosystems. These limitations are documented as reproducible inputs and can be revisited as the models and mappings mature. This version also does not benchmark DP-AWB against another tool, measure precision or recall against an expert gold standard, conduct an industrial user study, or report runtime and memory benchmarks. Those are distinct empirical evaluations and are planned future work; no scalability or operational-deployment claim is made here.

7. Conclusions

DP-AWB provides a reproducible instrument panel for Digital Passport model ecosystems. It supports model assessment before mature instance datasets exist, formalises use-case coverage as required items and joins, compares assessed ecosystems, records analyst-reviewed alignments, prioritises improvement targets, and produces integration recommendations. The battery DPP demonstration shows that the tool can turn a complex model comparison into design-time decision evidence: CE-RISE provides broader DPP infrastructure, BatteryPass provides focused battery-sector content, and a combined candidate composition can be emitted with explicit deduplication review items. Future work will extend the model-level workflow with data-driven validation of instance datasets, recurring violation analysis, constraint activation metrics, and information-preservation analysis for mappings between external models.

Author contributions

Riccardo Boero: conceptualisation, software, methodology, investigation, data curation, validation, visualisation, writing–original draft, writing–review and editing. Miguel Las Heras Hernández: conceptualisation, methodology, writing–review and editing.

Software availability

Software available from: PyPI. dpawb. https://pypi.org/project/dpawb/.

Source code available at: https://codeberg.org/CE-RISE-software/dp-assessment-workbench.

Zenodo, archived source code at: https://doi.org/10.5281/zenodo.20024117.[10]

Documentation available at: https://ce-rise-software.codeberg.page/dp-assessment-workbench/.

This project contains the following underlying software:

- dpawb v0.1.2 (DP Assessment Workbench Python package)
- io.github. CE-RISE-software/dpawb (MCP server; OCI image ghcr.io/ce-rise-software/dpawb-mcp:0.1.2, stdio transport, registered at https://registry.modelcontextprotocol.io/)

Software is available under the terms of the EUPL-1.2 license.

Ethics and consent

Ethical approval and consent were not required.

AI tool use

The authors used OpenAI ChatGPT and OpenAI Codex, based on the GPT-5 model, during manuscript preparation. These tools were used to support language editing, manuscript structuring, wording of the plain-language summary, preparation of submission metadata, and conversion checks between LaTeX and DOCX. The tools were not used to produce the deterministic assessment results reported in the article, to alter the underlying DP-AWB outputs, or to make final scientific judgements. The authors reviewed and edited the AI-assisted text and take full responsibility for the content of the manuscript.

Data availability

Zenodo. Battery DPP Demonstration Assessment Artefacts. https://doi.org/10.5281/zenodo.20024117.[17]

This project contains the following underlying data:

- assessment/profiles/ (Composition profiles used in the battery DPP assessment)
- assessment/use_cases/ (Battery DPP use-case file)
- assessment/converted/batterypass/1.2.0/ (BatteryPass-to-SHACL conversion script and generated SHACL proxy files)
- assessment/alignments/ (Reviewed alignment files)
- assessment/results/ (Persisted DP-AWB JSON result documents)
- assessment/replication-notes.md (Replication notes)

Data is available under the terms of the Creative Commons Attribution 4.0 International license.

Acknowledgements

The authors acknowledge the CE-RISE consortium and the developers and maintainers of the public CE-RISE and BatteryPass model resources used in the demonstration.

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Open Peer Review

Current Peer Review Status: ✔ ✘ ? ✘

Version 2

Reviewer Report 08 October 2026

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✘ **Pieter Pauwels**
Eindhoven University of Technology, Eindhoven, The Netherlands

This article presents a software tool (software tool article template), namely the DP-AWB, which is a SHACL-based assessment tool for digital passports. The article presents the tool itself, how it is built, the assessment method it implements, how to run the tool, and an example case of use.

I generally follow the points of the 4th reviewer of the first review round and I recommend 'Not Approved'

1. Rationale for developing the new software tool
- The introduction and general rationale throughout the article is very convoluted. The paper more often says what it does *not* do, then what it does do. Hence, the rationale needs to be deciphered by interpreting what the paper not says. It would be great if the article instead says what it does. I blame this feature to the excessive use of generative AI writing aids.
- From the introduction, the tool aims to evaluate digital product passports using SHACL shapes. Yet, the article hardly shows that, so I am not sure if this is really the case. The paper also argues that it does a comparison, yet it is not clear of what and why?
- The article hardly has any review of existing literature. This was indicated before, yet it was not remedied, except for some additional citations in the introduction mostly. This is not sufficient. Moreover, out of 17 references, 5 are self-citations (which is a about 1/3), 2 citations are references to the authors' project (so also self-cited), and 4 citations are to general standards and reference documents. That leaves 6 external scientific references, 4 of them journal papers (good, yet too few). That I find generally a too limited basis for making a rational argument. I recommend the authors to write out a proper Section 2 with Related Works. That would enable to better find and define the research gap in existing literature that this paper aims to address.
- Writing that 'this is the novelty to the best of our knowledge' (introduction) with such a small literature section, means that 'the knowledge' needs to be enlarged and enhanced, by incorporating literature and thus improving the authors' best of their knowledge.

2. Technical soundness
The technical part of this paper is limited mostly to Section 3.1.1, and I have several concerns on

these three short paragraphs.
- It is not clear why the authors focus on the 'property shapes' precisely, and why not on all shapes in the SHACL constraints.
- P (property shapes) is declared as a set, while C (all constraint statements) is declared as a number. Aren't these two equivalent, and should they not both be sets?
- Constraint density = C/|P|. Why are there vertical absolute value lines use here (|P|)? Is the value of P not by default positive? And does C not always have the same value as P? Is the number of constraint statements not the same as the number of property shapes? And if not, why focus on the property shapes? This needs a lot more detail and explanation. I have strong doubts about the usefulness of this equation.
- A better mathematical notation needs to be used to indicate what happens if P is zero.
- V_m should be properly formatted using subscript.
- URI IRIs is the wrong technical term
- It is not clear what a module is, and why one would need the set V of its URIs.
- It is also not clear why there is a U that is the union of the set of Vs. The union of a set is still just the same set. So technically U = V_m.
- What is R, what is v? The corresponding formula is similarly unclear.
- Why are "redundancy candidates calculated within and not across modules"? What are modules? What is within, and what is across? What does this sentence mean?
- The other sections do not have technical detail, which is really missing as a result.
- A good related works section with detail, might likely help set the technical background of this paper, making it easier to come up with the above formulas and terms.

3. Sufficient details of code, method and analysis to enable replication
- Section 2 documents the code and how it was built. Yet, this is without examples, explanations, and documentation. Hence, the details are not sufficient. It is indicated that results are deposited with the published code, and also that there is a core workflow with SHACL model sources and analyst-reviewed equivalences. It is however not clear what they are and what that means. To enable replication, more details need to be provided inside the paper, such that a reader can generally understand what happens and replicate the content. This is in my impression currently not possible. Fig. 1 does not help in this regard.
- In several parts of Section 2, statements are made about what is done, yet the details are not shown, and it is also not discussed or indicated why something is (not) done.
- Some details about 'the method' have been added to Section 3.1.1 (which can simply be left to Section 3.1), after the reviewer comments of round 1. Yet, these details are very unclear, and suspected to be not technically correct (see earlier comments). More precise procedural statements are needed, such that readers can follow these procedures like a recipe.
- Details are missing about the method in Sections 3.2-3.3.
- More details are available about the analysis / evaluation, which is the longest section (use case). However, without proper writing in the previous sections, it is very doubtful that the method effectively works, and what these analysis results really imply. The rationale needs to improve such that these results become more meaningful.

4. Sufficient information about results to allow supported conclusions
For me, the case study section on battery DPPs was something that I hoped would explain the rest of the paper, but it didn't. It is not clear what data is in the battery DPP, what the SHACL data is, and how it all works. I am sorry, perhaps it is all written and do I not have the correct background. Except that I think that I do, and that I should be able to understand what is proposed.

I thus also cannot agree that conclusions logically follow from the method and evaluation.

5. Other points
I find the amount of AI use excessive, leading to poor quality text: "our work does not do this, it does that". This is for me a big blocker to acceptance. It would be appreciated if the authors simply write down what they do, and with enthusiasm explain all their substeps. Doing so would already help so much with improving the readability of this article.

Is the rationale for developing the new software tool clearly explained?
No

Is the description of the software tool technically sound?
No

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?
No

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: semantic web technologies, construction technology, digital product passports, software development, database technology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 26 September 2026

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Syed Awais Hassan Munawar
University of Strathclyde, Glasgow, Scotland, UK

No further comments, amendments meet previous request.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My research areas are in industry 4.0, digital product passports for manufacturing/remanufacturing for high integrity sector with work on ReMake DPP

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 11 August 2026

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Omid Fatahi Valilai
[1] Constructor University Bremen, Bremen, Germany
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The manuscript introduces DP-AWB as an open-source SHACL-based workbench for assessing Digital Product Passport and Digital Material Passport model ecosystems, with functions covering structural assessment, use-case coverage, comparison, prioritisation, and composition recommendations. The software appears useful, reproducible, and practically relevant, particularly because it supports model-level analysis before representative instance data become available. The battery demonstration also provides a concrete application through the comparison of the CE-RISE ecosystem and BatteryPass. However, the current manuscript remains substantially closer to a software description and demonstration paper than to a sufficiently developed academic contribution.

A dedicated related-work section is required to position the approach against existing DPP interoperability studies, knowledge-graph validation approaches, SHACL assessment methods, ontology matching methods, semantic interoperability frameworks, and model-quality assessment approaches.

A major methodological concern concerns the current interpretation of **interoperability**. The framework presently operationalises interoperability mainly through object-reference properties, cross-module references, shared vocabulary overlap, and analyst-defined alignment pairs. These measures are useful structural diagnostics, but they do not demonstrate semantic or operational interoperability. The manuscript should therefore extend the conceptual model of interoperability beyond SHACL-level connectivity. DPPs do not operate as isolated semantic artefacts but must exchange information with operational enterprise and supply-chain systems such as ERP, MES, PLM, WMS, SCM, IoT platforms, lifecycle databases, compliance systems, and external DPP

registries.

Figure 1 is useful as a high-level instrument-panel representation, but it should evolve into a methodological architecture showing inputs, semantic processing, assessment functions, decision logic.

The authors should provide explicit mathematical or algorithmic definitions for important metrics such as constraint density, shared-vocabulary ratio, redundancy candidates, coverage classification, prioritisation score, and composition recommendation logic rather than describing them primarily in narrative form.

The Conclusions currently state that DP-AWB can turn model comparison into "*actionable evidence*," but this claim should be moderated until its recommendations are demonstrated within a real DPP integration or operational deployment.

Is the rationale for developing the new software tool clearly explained?
Partly

Is the description of the software tool technically sound?
Partly

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?
Yes

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Digital Transformation, Digital product passport

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 25 Aug 2026

Riccardo Boero

We thank the reiewer for the constructive assessment and for recognising the usefulness, reproducibility, and design-time relevance of DP-AWB. We agree that the original paper needed clearer positioning, more explicit definitions of the reported outputs, and more careful wording about what SHACL-level evidence can establish. The revisions strengthen those points while retaining the deliberately limited scope of this Software Tool Article.

Comment 1 — Related-work positioning
The reviewer requests a dedicated related-work section positioning the approach against DPP interoperability studies, knowledge-graph validation, SHACL assessment, ontology matching, semantic-interoperability frameworks, and model-quality assessment.

Response: We agree that the original positioning was insufficient. The revised Introduction now locates DP-AWB with respect to DPP ecosystem and requirements research, DPP ontology/SHACL development, SHACL data-graph validation, ontology-quality assessment, schema matching, and ontology matching. The text also narrows the contribution claim: DP-AWB does not claim to replace those fields or to establish semantic interoperability. Its contribution is an open, deterministic workflow that combines SHACL shape-graph assessment, lexical-structural use-case coverage, analyst-authored alignment checking, prioritisation, and candidate-composition review for evolving DPP model ecosystems before instance-data validation is available. **Location in Version 2:** Introduction; references 11–17.

Comment 2 — Interoperability interpretation and operational DPP systems
The reviewer notes that object references, cross-module references, vocabulary overlap, and analyst-defined alignment pairs are structural diagnostics rather than demonstrations of semantic or operational interoperability, and requests extension to enterprise and supply-chain systems.

Response: We agree with the distinction and have made it explicit. The revised Discussion identifies object references, cross-module references, and literal IRI reuse as syntactic/structural signals only. It states that semantic interoperability requires justified concept mappings and agreement on meaning, units, lifecycle boundaries, and regulatory interpretation; operational interoperability requires runtime mechanisms such as identifiers, provenance, access control, synchronization, and data exchange. We respectfully do not extend the paper into an ERP/MES/PLM/IoT or supply-chain integration architecture. DP-AWB is not a DPP runtime, data-space connector, or deployment framework. Its versioned inputs are SHACL model profiles, and it produces design-time evidence about those models. Evaluating operational integration would require a different empirical object, protocol, and evidence base. The revised text makes this boundary clear rather than implying that the present results validate deployment. **Location in Version 2:** Introduction; Section 6, Discussion; Conclusion.

Comment 3 — Figure 1 as a methodological architecture
The reviewer finds Figure 1 useful but suggests evolving it into an architecture showing inputs, semantic processing, assessment functions, and decision logic.

Response: Thank you for the suggestion. We considered it carefully, but we have retained Figure 1 in its current form. It intentionally presents the workbench's complementary evidence perspectives, whereas Figure 2 presents the deterministic file-based workflow. Combining the two would duplicate Figure 2's role and make the instrument-panel figure less clear. More importantly, a "semantic processing" layer would be inaccurate for DP-AWB: its coverage procedure is deliberately lexical-structural and does not perform ontology reasoning, embedding-based similarity, large-language-model similarity, or general

semantic-equivalence determination. Rather than introduce a misleading architecture diagram, we strengthened the textual method description. Section 2.3 describes inputs and persisted JSON outputs; Section 3.1.1 defines core metrics; Sections 3.2–3.4 give the coverage, comparison, prioritisation, and candidate-composition rules. The figures and their captions are retained as published in v1. **Location in Version 2:** Sections 2.3 and 3.1.1–3.4.

Comment 4 — Explicit definitions of metrics and decision rules
The reviewer requests mathematical or algorithmic definitions for constraint density, shared-vocabulary ratio, redundancy candidates, coverage classification, prioritisation score, and composition recommendation.

Response: We agree. New Section 3.1.1 now defines constraint density as the number of released-set SHACL constraint statements divided by the number of property shapes, and shared-vocabulary ratio as repeated URI IRIs divided by the union of URI IRIs across supplied modules, including their zero-denominator behaviour. It also defines the conservative six-element signature used to surface within-module redundancy candidates: sh:path, sh:datatype, sh:class, sh:node, sh:minCount, and sh:maxCount. Section 3.2 provides the deterministic lexical-structural coverage classification procedure, including direct-token evidence, structural support, partial evidence, indeterminate single-token evidence, and join conditions. Section 3.4 now records the fixed prioritisation rank bases and states that the displayed priority rank is merely the ordinal order after sorting by rank basis and identifier, not a weighted composite score. It also states the fixed 0–3 coverage values used to select a preferred side of an analyst-declared duplicate, while making clear that every input module is retained in the candidate profile. Complete executable definitions and output traces remain available in the archived source and replication package. **Location in Version 2:** Sections 3.1.1–3.4; Data availability; replication package.

Comment 5 — Scope of the conclusion
The reviewer asks that the conclusion moderate the phrase "actionable evidence" until recommendations have been demonstrated in a real DPP integration or deployment.

Response: We agree. The revised Conclusion now describes DP-AWB's output as **design-time decision evidence** and characterises composition output as a candidate profile that requires domain and system-integration review. The Discussion explicitly states that the current study does not demonstrate a deployed DPP integration, operational decision, instance-data validation, or runtime interoperability. **Location in Version 2:** Section 6, Discussion; Conclusion.

We appreciate the reviewer's comments. The revised paper is clearer about its contribution as reproducible software for design-time assessment of SHACL model ecosystems, and more explicit about the boundaries between structural diagnostics, semantic interpretation, and operational deployment.

Competing Interests: No competing interests were disclosed.

Reviewer Report 06 August 2026

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Foivos Psarommatis
[1] University of Oslo, Oslo, Norway
[2] University of Oslo, Oslo, Norway

- The literature review is almost absent. The paper provides only ten references, most of which concern CE-RISE, BatteryPass, the software repository, or the replication package rather than peer-reviewed scientific literature.
- The paper does not adequately position DP-AWB against existing work on:
  - Digital Product Passport architectures;
  - SHACL validation and ontology-quality assessment;
  - semantic interoperability;
  - schema matching and ontology alignment;
  - model-comparison tools;
  - DPP implementation in manufacturing and circular supply chains.
- The scientific novelty is insufficiently demonstrated. It is unclear which functions are fundamentally new compared with existing SHACL analysis, ontology evaluation, schema-comparison, and validation tools.
- The proposed solution is highly theoretical and model centric. It assesses SHACL specifications but does not demonstrate that the resulting recommendations improve an operational DPP implementation.
- The paper treats the DPP primarily as a static data structure or collection of fields. In practice, a DPP is a dynamic information system that must continuously receive lifecycle events and data from multiple organisations and systems.
- There is no explanation of how DPP data would be collected from:
  - ERP, MES, PLM and supply-chain systems;
  - manufacturing equipment and IoT sensors;
  - inspection and quality-control systems;
  - maintenance, repair and recycling operations;
  - operators and external stakeholders.
- There is very little discussion of the technical mechanisms required for real DPP operation, such as APIs, event-based data exchange, identifiers, data carriers, data transformation, system connectors and data synchronization.
- The paper does not address important operational aspects such as data ownership, access rights, confidentiality, authentication, provenance, timestamps, version control and distributed stakeholder participation.
- The tool evaluates only the declared SHACL model, not whether the required information

can actually be generated, accessed, exchanged or maintained during the product lifecycle.

- No real product, manufacturing process, company, battery, supply chain or DPP instance dataset is used. Therefore, the practical value of the assessment remains unverified.
- No industrial pilot or user evaluation is presented. The paper does not show whether model developers, manufacturers, DPP providers or system integrators find the outputs useful.
- The BatteryPass model is converted into an inferred SHACL proxy, while CE-RISE is assessed using its native SHACL models. This creates a methodological asymmetry that may substantially affect the comparison.
- The BatteryPass-to-SHACL conversion methodology is not described in sufficient technical detail. The paper should explain:
  - the conversion rules;
  - which SAMM constructs were retained or lost;
  - how cardinalities and datatypes were inferred;
  - how conversion correctness was validated;
  - how the proxy differs from the original model.
- The paper acknowledges that matching is based on SHACL evidence, but the precise matching method is unclear. It should explicitly explain that coverage relies mainly on keyword, token or structural matching rather than genuine semantic reasoning.
- The algorithms behind the main functions are insufficiently documented. The paper does not clearly explain how coverage, compare, prioritize and recommend composition calculate their results.
- The prioritisation logic is unclear. The criteria, weights, thresholds and ranking formula used to identify “prioritised improvement targets” are not adequately presented.
- The composition recommendation is also insufficiently explained. Retaining all 12 CE-RISE modules and all seven BatteryPass modules produces a 19-module composition, but this is closer to model aggregation than a validated integration solution.
- The paper identifies duplicate concepts but does not technically demonstrate how they would be reconciled. It does not provide mappings, transformation rules, canonical concepts or conflict-resolution mechanisms.
- The manually prepared alignment contains only 18 candidate pairs, of which 14 are retained. This is a very small and non-exhaustive alignment relative to models containing thousands of shapes and properties.
- The reported alignment coverage ratio of 1.0 is not particularly meaningful because it only indicates that the 14 manually selected pairs were found in both models. It does not measure overall alignment completeness or recall.
- The battery use-case requirements are not sufficiently justified. The origin of the required information items and joins is unclear, and there is no evidence that they were validated by industrial or regulatory experts.
- Table 5 reports a very high number of indeterminate findings, especially 45 for CE-RISE. This considerably limits the interpretability of the coverage assessment and requires much deeper analysis.
- The structural metrics mainly count modules, node shapes, property shapes and references. A larger number of shapes does not necessarily indicate better coverage, quality or practical usability.
- Metrics such as typed-property share and cardinality-bounded share are useful but insufficient for evaluating whether a DPP model is semantically correct, regulatorily compliant or operationally implementable.

- The comparison may unintentionally favour larger models by presenting structural breadth as stronger lifecycle coverage without validating the relevance or quality of the included concepts.
- The 132 CE-RISE “redundancy candidates” are not investigated. The paper does not determine whether these are actual modelling problems, intentional repeated patterns or false positives.
- There is no benchmark against another assessment tool, expert manual assessment or established ontology-quality framework.
- There is no quantitative validation of the tool’s accuracy, such as precision, recall, false-positive rate or agreement with domain experts.
- Scalability is claimed but not demonstrated. No execution time, memory consumption, computational complexity or performance results are reported for the 1,515 node shapes and 4,321 property shapes.
- The article provides conceptual diagrams, but no meaningful examples of the actual JSON outputs, user interface, prioritisation report or integration recommendation produced by the software.
- The discussion does not sufficiently distinguish between:
  - syntactic interoperability;
  - structural compatibility;
  - semantic interoperability;
  - operational interoperability.
- SHACL conformity alone cannot establish semantic interoperability. Models may use similar fields while assigning different meanings, units, lifecycle boundaries or regulatory interpretations.
- The conclusions overstate the practical applicability of the results by referring to “actionable evidence,” although no real integration, deployment or operational decision is demonstrated.

Is the rationale for developing the new software tool clearly explained?

No

Is the description of the software tool technically sound?

Partly

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?

No

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: DPP expert, traceabilty expert

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 25 Aug 2026

Riccardo Boero

We thank the reviewer for the detailed and wide-ranging report. The comments raise two different classes of issue: (i) documentation and interpretation of the software tool, which we have strengthened in the revised manuscript; and (ii) requirements for a deployed, operational Digital Product Passport (DPP) system, which are important but outside the stated purpose of this design-time SHACL model-assessment tool.
We respond to both classes explicitly below. Scope clarification DP-AWB is not presented as a DPP runtime, data-space connector, passport issuer, or implementation reference architecture. It is a deterministic design-time workbench that evaluates declared SHACL model specifications before representative instance data are necessarily available. It therefore provides evidence about model structure, declared constraints, lexical-structural use-case coverage, and analyst-reviewed overlap candidates. It does not evaluate the operational generation, access, exchange, synchronization, governance, or lifecycle maintenance of DPP instance data. Treating those distinct evaluation questions as a prerequisite for this tool would conflate model-assessment software with a full operational DPP deployment study. The revised manuscript now states this boundary more directly.

Comment 1 — Related work, positioning, and novelty **The reviewer states that the literature review is almost absent; that the paper does not position DP-AWB against DPP architectures, SHACL validation and ontology-quality assessment, semantic interoperability, schema matching and ontology alignment, model-comparison tools, and DPP implementation; and that the scientific novelty is insufficiently demonstrated.**

Response: We agree that the original literature positioning was too limited. The revised Introduction now distinguishes: DPP ecosystem and architecture research; DPP ontology and SHACL work; DPP-system requirements research; SHACL data-graph validation; ontology-quality assessment; schema matching; and ontology matching. We added the corresponding references, including Jansen *et al.* on DPP-system requirements, Rahm and Bernstein on schema matching, Shvaiko and Euzenat on ontology matching, and Tartir *et al.* on ontology-quality metrics. The revised text also narrows the novelty claim. DP-AWB does **not** claim to invent SHACL validation, ontology evaluation, schema matching, ontology alignment, or operational DPP architecture. Its contribution is the implemented, open, deterministic workflow that combines shape-graph assessment, declared use-case coverage evidence, comparison, analyst-reviewed alignment checking, prioritisation, and candidate-composition review for DPP model ecosystems before instance-data validation is possible. This is a software-tool contribution with explicit, reproducible inputs and outputs, not a claim of a new general theory of semantic interoperability. **Location in Version 2:** Introduction; references 11–17.

Comment 2 — Requests for operational DPP deployment mechanisms **The reviewer characterises the solution as highly theoretical and model-centric; states that a DPP is dynamic rather than a static collection of fields; and requests discussion of ERP, MES, PLM, supply-chain systems, equipment and IoT sensors, quality-control systems, repair and recycling operations, APIs, event exchange, identifiers, data carriers, connectors, synchronization, data ownership, access control, confidentiality, authentication, provenance, timestamps, version control, and stakeholder participation.**

Response: We respectfully disagree that the absence of those mechanisms is a defect in the present article. They are requirements for an operational DPP system, not for a tool that analyses DPP **model specifications**. Indeed, the revised Introduction now cites DPP-system requirements literature precisely to acknowledge this distinction. DP-AWB neither ingests enterprise or sensor data nor claims to operate a passport at runtime; its input is a versioned SHACL model profile. Its purpose is to make model-level design evidence available before a runtime system and mature instance datasets exist. The revision now distinguishes the relevant layers explicitly. Shared vocabulary, object references, and cross-module references are syntactic and structural signals only. Semantic interoperability requires justified concept mappings and agreement on units, lifecycle boundaries, and regulatory interpretation. Operational interoperability requires runtime identity, access-control, provenance, synchronization, and data-exchange mechanisms. DP-AWB can inform later design decisions at those layers, but it neither evaluates nor implements them. An ERP/IoT/DPP deployment evaluation would be valuable future work, but it is a different research object and cannot be presented as a missing validation step for this software tool. **Location in Version 2:** Introduction; Section 6, Discussion.

Comment 3 — Instance data, industrial pilots, and user evaluation
The reviewer notes that the tool evaluates declared SHACL models rather than whether information can be generated, accessed, exchanged, or maintained; and requests a real product, company, battery, supply chain, DPP instance dataset, industrial pilot, or user evaluation.

Response: This limitation is intentional and central to the rationale for DP-AWB: model developers need to inspect evolving specifications before representative data exist. The article does not claim that the reported model-level evidence proves successful DPP deployment, improves a real operational DPP, or validates data collection and exchange. We have reinforced that boundary in the Discussion and replaced the potentially broad phrase “actionable evidence” in the Conclusion with “design-time decision evidence.” The battery case nevertheless uses real, version-pinned published CE-RISE and BatteryPass model sources, plus persisted assessment, comparison, coverage, prioritisation, and composition-result documents. That is an appropriate reproducible use case for a Software Tool Article. Industrial/user validation, data-driven conformance validation, and runtime performance studies are explicitly identified as future empirical work rather than implied by the present results. **Location in Version 2:** Sections 5.1 and 6; Conclusion; Data availability.

Comment 4 — BatteryPass proxy asymmetry and conversion method
The reviewer notes the asymmetry between native CE-RISE SHACL and the inferred

BatteryPass proxy, and requests conversion rules, retained or lost SAMM constructs, cardinality and datatype inference, conversion validation, and differences from the original model.

Response: We agree that the conversion method needed fuller documentation. Section 5.2 now states that the seven selected BatteryPass v1.2.0 SAMM/RDF Turtle modules were converted deterministically. It specifies the principal mappings: SAMM Aspects and Entities to SHACL NodeShapes while retaining IRIs; SAMM properties to sh:path; optionality to sh:minCount; non-list characteristics to sh:maxCount; and characteristic-derived datatypes, entity references, lists, enumerations, regular expressions, ranges, inheritance, labels, descriptions, examples, units, and source links to corresponding SHACL constraints or trace annotations. We also now state the asymmetry more strongly: the generated files are not official BatteryPass SHACL publications, and inferred cardinalities and SHACL renderings can affect shape-level metrics. The copied Turtle sources, deterministic converter, generated proxies, profiles, and results are archived together. The proxies parse as Turtle and are accepted by the DP-AWB assessment workflow; this is a reproducibility and processing check, not a claim that a BatteryPass maintainer has semantically certified an official SHACL conversion. The revised manuscript therefore treats the comparison as a transparent proxy assessment, not as an official SHACL comparison. **Location in Version 2:** Section 5.2; Data availability; replication package.

Comment 5 — Matching, algorithms, prioritisation, and composition recommendation
The reviewer asks for clarification that coverage uses keyword/token or structural matching rather than semantic reasoning; requests algorithms for coverage, comparison, prioritisation, and composition recommendation; questions prioritisation criteria, weights, thresholds, and ranking; and characterises the 19-module output as aggregation rather than a validated integration solution.

Response: We agree that the decision rules should be visible in the article rather than only in the source code and result schemas. New Section 3.1.1 defines the core structural metrics and the conservative redundancy signature. Section 3.2 now defines coverage as a deterministic lexical-structural procedure, not semantic matching. It normalises and tokenises declared identifiers and labels, compares them with SHACL IRIs, labels, property paths, owner shapes, and target classes, and uses a small explicit lexical-variant list. It does not use ontology reasoning, embeddings, LLM similarity, external vocabulary lookup, or general semantic-equivalence determination. A direct join additionally requires shared owner-shape evidence or an explicit object-reference path. New Section 3.4 documents the remaining operations. compare uses the shared declared scope and fixed metric-delta ordering; it has no overall model-quality score. prioritize uses fixed, disclosed rank bases and rule traces, with no learned model, hidden weights, or expert-derived numerical scoring. recommend_composition emits a candidate profile and review items; it is deliberately not an automatic merge, mapping generator, canonical-model generator, or conflict-resolution engine. We agree with the reviewer's description of the 19-module result as an aggregation candidate rather than a validated integrated model. This is exactly why the revised text now uses "candidate profile," "deduplication review item," and "design-time decision evidence," and states that implementation requires human domain and system-integration review. The tool never claimed to generate executable transformations or

resolve duplicate concepts automatically. **Location in Version 2:** Abstract; Plain language summary; Sections 3.1.1–3.4; Section 5.6; Section 6; Conclusion.

Comment 6 — Alignment scope and the interpretation of the alignment ratio
The reviewer notes that 18 candidate pairs and 14 retained pairs are non-exhaustive for models with thousands of shapes, and that an alignment coverage ratio of 1.0 only shows that selected pairs were found on both sides rather than measuring alignment completeness or recall.

Response: We agree. The manuscript already stated that the seed alignment was bounded and non-exhaustive, and that the ratio measured coverage of the declared reviewed alignment rather than recall over all possible overlaps. New Section 3.4 now states the calculation directly: bilateral presence of declared pairs divided by the number of declared pairs. It explicitly states that this is not a recall or completeness estimate. The small alignment is intentional: its role is not to claim exhaustive semantic mapping, but to demonstrate a conservative, inspectable human-review step before deduplication candidates are surfaced. DP-AWB does not infer semantic correspondences automatically. Exhaustive alignment, transformation rules, and conflict resolution are separate ontology-engineering tasks and should not be represented by a mechanically inflated match count. **Location in Version 2:** Sections 3.3–3.4 and 5.6.

Comment 7 — Use-case basis, indeterminate results, structural metrics, and redundancy candidates
The reviewer questions the origin and validation of the battery use-case requirements; asks for deeper analysis of the 45 indeterminate CE-RISE findings; warns that model-size metrics do not prove quality, semantic correctness, compliance, or operational implementability; raises possible size bias; and asks whether the 132 redundancy candidates are actual problems.

Response: We agree that the status of the battery use case required clearer statement. Section 5.1 now identifies it as an author-defined analytical demonstration, not an exhaustive regulatory checklist or an industrially validated requirements specification. Its versioned requirement file and application-scope note are openly deposited so that users can inspect, replace, or stakeholder-validate the requirements for another application. The case is intended to exercise the workflow across a broad battery DPP model scope, not to establish regulatory conformance. We have also expanded Table 5's interpretation. The 45 CE-RISE indeterminate findings are separated into 11 item-level findings with only partial lexical evidence and 34 join-level findings where an endpoint is indeterminate or the matched endpoints lack a shared owner shape or explicit object-reference path. They are a conservative review queue, not evidence that the information is absent or that an implementation is impossible. We respectfully disagree with any interpretation of the structural metrics as quality scores. The manuscript explicitly says that more shapes, higher typed-property share, and higher cardinality-bounded share do not establish that a model is better, more complete, semantically correct, regulatorily compliant, or operationally implementable. The comparison is framed as evidence of different modelling roles, not a size-based ranking. Similarly, the 132 redundancy candidates are reported as conservative inspection targets, not confirmed defects or false-positive-free findings; the tool's output

supplies the traces needed for subsequent model-author review. **Location in Version 2:** Sections 5.1, 5.3–5.5, and 6; Table 5; Data availability.

Comment 8 — Benchmarking, performance, outputs, and conclusion scope
The reviewer requests benchmarking against other tools, expert/manual assessment, or ontology-quality frameworks; precision, recall, false-positive, and expert-agreement measures; execution-time, memory, and complexity results; more examples of JSON outputs; a distinction among syntactic, structural, semantic, and operational interoperability; and less broad practical conclusions.

Response: The reviewer is correct that this Version 2 does not provide a benchmark, expert gold-standard evaluation, precision/recall study, industrial user study, or runtime/memory benchmark. We have made that explicit in the limitations rather than implying such validation. These studies evaluate different claims: matching accuracy requires an authoritative alignment corpus; operational utility requires an industrial or user-study protocol; and performance requires a defined workload and hardware protocol. We consider them appropriate future work, not results that can be inferred from the present design-time demonstration. We have, however, improved the software-article documentation that can be provided now. Section 2.3 describes the common JSON result envelope and gives the structure and trace content of a coverage output; complete persisted JSON documents are in the replication package. The revised Discussion distinguishes syntactic/structural signals from semantic and operational interoperability. The Conclusion now refers to “design-time decision evidence” rather than implying a demonstrated deployment outcome. **Location in Version 2:** Section 2.3; Section 6; Conclusion; Data availability.

We appreciate the reviewer’s detailed comments. The revisions make the tool’s documented methods, output interpretation, and scope boundaries clearer, while preserving the deliberately limited and reproducible purpose of this Software Tool Article.

Competing Interests: No competing interests were disclosed.

Reviewer Report 23 July 2026

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The article presents DP-AWB, an open-source tool that calculates metrics of structure, explicitness,

interoperability and maintainability from SHACL shape files directly, as well as SHACL-only use-case coverage, cross-ecosystem comparison, prioritisation and composition recommendation all without instance data.

Points that author must address:
1- Related work/literature positioning is absent
2- BatteryPass conversion methodology should be mentioned
3-The article should make it clear its keyword/token matching and not semantic
4- Indeterminate data from table 5 should be discussed further
None of these individually undermine the contribution the tool and this approach is a real step forward for future deployment of DPP ecosystem.

Is the rationale for developing the new software tool clearly explained?
Yes

Is the description of the software tool technically sound?
Partly

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?
Yes

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My research areas are in industry 4.0, digital product passports for manufacturing/remanufacturing for high integrity sector with work on ReMake DPP

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 25 Aug 2026

Riccardo Boero

We thank the reviewer for the positive assessment of DP-AWB and for the constructive, clearly focused recommendations. We have revised the manuscript to address each of the four points below.

Comment 1
Related work/literature positioning is absent.

Response: We agree. The Introduction now includes a related-work positioning discussion.

It cites literature that frames Digital Product Passports as ecosystems with lifecycle, governance, and interoperability requirements, and a recent cross-sectoral DPP ontology and SHACL work. It also cites the W3C SHACL Recommendation. The revised text explains that DP-AWB is complementary to DPP ontology design and conventional SHACL validation: it does not propose another DPP schema or validate instance data, but analyses the structure and declared constraints of SHACL shape graphs before representative data are available. It positions the contribution as the combination of shape-graph assessment, use-case coverage evidence, analyst-reviewed alignments, and composition guidance.
Location in Version 2: Introduction; references 11–13.

Comment 2
BatteryPass conversion methodology should be mentioned.

Response: We agree. Section 5.2 now documents the deterministic conversion of the seven selected BatteryPass v1.2.0 SAMM/RDF Turtle modules to inferred SHACL proxies. The manuscript states that SAMM Aspects and Entities become SHACL NodeShapes while retaining their IRIs; SAMM properties become SHACL properties using the original property IRI as sh:path; and optionality, cardinality, datatypes, entity references, list characteristics, enumerations, regular expressions, ranges, inheritance, labels, descriptions, examples, units, and source links are retained or mapped to SHACL constraints or trace annotations. The revision also states explicitly that these are generated proxies rather than official BatteryPass SHACL publications, that conversion assumptions can affect shape-level metrics, and that the copied sources, generated proxies, and converter are available in the replication archive. **Location in Version 2:** Section 5.2, *Compared ecosystems*; Data availability.

Comment 3

The article should make it clear its keyword/token matching and not semantic.

Response: We agree and have made this methodological boundary explicit. Section 3.2 now defines coverage as a deterministic lexical-structural procedure. It tokenises and normalises required-item identifiers and labels, compares them with declared SHACL IRIs, labels, property paths, owner shapes, and target classes, and uses only a small, explicit set of lexical variants (for example, identifier/id). It does not use ontology reasoning, embeddings, large-language-model similarity, external vocabulary lookup, or general semantic-equivalence determination. A direct join additionally requires shared owner-shape evidence or an explicit object-reference path. Semantic equivalences for deduplication remain analyst-authored and separately reviewed. This distinction is also stated in the Abstract, Plain language summary, Table 5 interpretation, and Discussion.
Location in Version 2: Abstract; Plain language summary; Section 3.2, *Coverage model*; Section 5.5; Discussion.

Comment 4

Indeterminate data from Table 5 should be discussed further.

Response: We agree. Section 5.5 now explains the 45 indeterminate CE-RISE findings rather than treating them as an undifferentiated count. Eleven are item-level findings where only partial lexical evidence was found for battery-specific requirements (including battery chemistry, carbon-footprint concepts, compliance declarations, dismantling information, and hazardous substances). The remaining 34 are join findings: either an endpoint is indeterminate or both endpoints are matched but the SHACL profile contains neither a shared owner shape nor an explicit object-reference path. The revised text explains that these findings do not establish absence of the information or impossibility of implementation. They are a review queue that may indicate a need for a more precise use-case statement, a battery-specific mapping, an explicit SHACL relationship, or a narrowly documented analyst alignment. Table 5 has also been retitled to identify its results as lexical-structural coverage evidence.
Location in Version 2: Section 5.5, *Coverage results*; Table 5; Discussion. We appreciate the reviewer's conclusion that the tool and approach are a useful step towards future DPP ecosystem deployment. The revision makes the scope, reproducibility, and interpretation of the reported evidence more transparent.

Competing Interests: No competing interests were disclosed.