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A Safety-Aware Retrospective Audit of a Certainty-Factor Expert System for Formalin-Risk Screening

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ABSTRACT

Observable characteristics can support early food-safety triage, but they cannot chemically confirm formaldehyde. This study presents a safety-aware retrospective technical audit and algorithmic reconstruction of a legacy web-based certainty-factor (CF) expert system previously used as a prototype for food screening. The available evidence comprised interface artifacts, a food-category summary, legacy rule values, and one manually reconstructable fish scenario; source code, laboratory measurements, and a detailed fish calculation trace were unavailable. Expert and user CF values were multiplied for each positive evidence item and aggregated iteratively. The fish contributions of 0.42, 0.40, 0.12, and 0.28 produced an exact reconstructed score of 0.7795072, consistent only with the prototype summary value of 78%; a detailed interface-level trace for fish could not be verified. A deterministic verification suite confirmed expected behavior for empty, zero, unit, single-evidence, order-invariance, and invalid-input cases in the reconstructed reference algorithm. The audit also identified unsafe legacy remediation text and insufficient rule provenance. The revised architecture therefore separates screening from laboratory confirmation and introduces versioned rules, input snapshots, calculation lineage, and referral records. The contribution is a transparent audit framework for legacy rule-based screening systems. The CF score remains a rule-consistency measure and must not be interpreted as formalin concentration, contamination probability, predictive accuracy, or a substitute for validated chemical testing.

Keywords— certainty factor; explainable expert system; food safety; formalin; retrospective audit; risk screening

ABSTRAK

Karakteristik yang dapat diamati dapat mendukung triase awal keamanan pangan, tetapi tidak dapat mengonfirmasi formaldehida secara kimia. Penelitian ini menyajikan audit teknis retrospektif yang berorientasi keselamatan serta rekonstruksi algoritmik terhadap prototipe lama sistem pakar berbasis web dengan metode Certainty Factor (CF). Bukti yang tersedia terdiri atas artefak antarmuka, ringkasan kategori pangan, nilai aturan lama, dan satu skenario ikan yang dapat direkonstruksi secara manual; kode sumber, pengukuran laboratorium, dan jejak perhitungan terperinci untuk ikan tidak tersedia. Nilai CF pakar dan pengguna dikalikan untuk setiap bukti positif, kemudian diagregasikan secara iteratif. Kontribusi skenario ikan sebesar 0,42; 0,40; 0,12; dan 0,28 menghasilkan skor rekonstruksi tepat 0,7795072, yang hanya konsisten dengan nilai ringkasan prototipe sebesar 78%; jejak perhitungan ikan pada tingkat antarmuka tidak dapat diverifikasi. Serangkaian uji deterministik mengonfirmasi perilaku algoritma rekonstruksi untuk kasus kosong, nol, satu, bukti tunggal, perubahan urutan, dan input tidak valid. Audit juga menemukan teks mitigasi lama yang tidak aman dan asal-usul bobot aturan yang tidak memadai. Arsitektur revisi memisahkan skrining dari konfirmasi laboratorium serta menambahkan versi aturan, snapshot input, jejak perhitungan, dan catatan rujukan. Skor CF tetap merupakan ukuran konsistensi terhadap aturan dan bukan kadar formalin, probabilitas kontaminasi, akurasi prediktif, atau pengganti pengujian kimia tervalidasi.

Kata kunci— audit retrospektif; faktor kepastian; formalin; keamanan pangan; skrining risiko; sistem pakar

1. INTRODUCTION

The illegal addition of formalin to food remains a food-safety concern because it can delay spoilage and alter observable properties while exposing consumers to avoidable health risks. Recent reviews distinguish deliberately added formalin from naturally occurring formaldehyde and emphasize that endogenous formation, matrix effects, and variable analytical sensitivity complicate interpretation [1]–[4]. Visual, tactile, or organoleptic cues must therefore be treated as warning signs rather than confirmatory measurements.

Laboratory and sensor-based approaches—including chromatography, electrochemical sensing, optical techniques, and rapid field kits—remain the evidentiary foundation for determining formaldehyde in food [5]–[11]. These methods differ in cost, portability, detection limits, selectivity, and sample-preparation requirements. Their availability does not eliminate the operational need for transparent triage when inspection resources are limited, but triage cannot be represented as chemical detection.

Rule-based systems can support this narrow task because they expose the relationship between evidence, expert weights, and resulting belief. Certainty-factor inference has been applied to formalin and borax screening, hazardous-compound identification, meat classification, and other knowledge-based tasks [12]–[16]. Nevertheless, many implementations conflate a belief score with diagnostic accuracy, provide only isolated screenshots, or omit the provenance and safety boundaries required for public-service use.

The legacy prototype examined here was developed for the Cirebon City Health Office and contains food categories, physical indicators, expert and user CF values, and a web interface. Its earlier interpretation treated a 78% output too broadly as identification of formalin content. The present study instead asks: what conclusions are supportable from the surviving computational artifacts, and what data and safety controls are required for an auditable screening workflow?

This study makes three contributions. First, it reconstructs and verifies the positive-evidence CF calculation while explicitly distinguishing arithmetic consistency from chemical or predictive validity. Second, it performs a cross-artifact and safety audit that documents both supported claims and unresolved inconsistencies. Third, it proposes a versioned consultation data model and laboratory-referral boundary suitable for future implementation and empirical validation. The study evaluates a retrospective evidence package; it does not claim that the proposed architecture has already been deployed.

2. RELATED WORK AND RESEARCH GAP

Research on formaldehyde in food increasingly emphasizes validated analytical techniques. Fappiano et al. [5] compared conventional analytical approaches with sensing methods across the agri-food chain. Torrarit et al. [10] reported an amperometric seafood measurement platform, whereas Wang et al. [9] developed an interference-resistant surface-enhanced Raman spectroscopy method. These studies generate measurement evidence; a CF system does not. Rule-based triage may precede chemical confirmation, but it cannot replace it.

The closest computational studies demonstrate both utility and limitations. Sovia and Ginting [12] applied CF to formalin identification in a near-identical domain. Sihotang et al. [13] combined CF reasoning with formalin and borax cases, while Kholil and Nurcahyo [14] retained laboratory examination as the final solution. Kusnadi et al. [15] evaluated a CF-based meat-classification system on 30 labeled samples, illustrating that accuracy requires comparison with known labels. Azmi et al. [16] further demonstrate contemporary use of CF for graded decision support, although domain-specific validation remains essential.

The unresolved gap is not the absence of a CF formula or a web interface. It is the absence of a transparent audit that distinguishes reconstructable computation from unavailable evidence, identifies unsafe legacy functions, and specifies the lineage needed to reproduce historical results after rule updates. This study addresses that gap without presenting the legacy score as laboratory evidence.

TABLE 1. Positioning of the study against the closest literature

Study	Domain and method	Evaluation evidence	Remaining distinction
Sovia and Ginting [12]	Formalin; CF expert system	Worked rules and interface	Near-identical domain; limited validation and safety boundary
Sihotang et al. [13]	Formalin and borax; CF	Laboratory values plus CF cases	Broader chemicals; limited operational lineage
Kholil and Nurcahyo [14]	Four hazardous compounds; backward chaining	Rule matching and laboratory referral	No graded CF belief score
Kusnadi et al. [15]	Meat classification; CF	30 labeled samples; 90% agreement	Different target and institutional context
Present audit	Four food types; retrospective CF reconstruction	Arithmetic audit, evidence-coherence check, deterministic test suite, safety inspection	No source code or laboratory dataset; proposed architecture not yet implemented

3. MATERIALS AND METHODS

3.1. Research Design and Evidence Scope

The study used a retrospective technical-audit design. The evidence package comprised the surviving manuscript, interface images, a category-level CF summary, encoded physical indicators, and numeric values associated with a reconstructable fish scenario. The source code, database export, executable deployment, detailed fish trace, expert-elicitation records, human-user study, laboratory measurements, and labeled specimen dataset were not available. Accordingly, the unit of analysis was the documented inference transaction rather than a food specimen or software user.

The audit separated three evidence levels: (1) directly visible interface content; (2) independently reconstructable arithmetic; and (3) proposed safeguards or data structures that were not demonstrated in the legacy implementation. A claim was accepted only at the strongest level supported by the available artifact. Summary-level numerical agreement was not described as a verified interface trace, and proposed controls were not described as deployed features.

3.2. Food Categories and Safety Boundary

The legacy knowledge base covered fish, tofu, meatballs, and wet noodles. The encoded criteria were retained solely as archival inputs for reconstruction. They were not treated as universally valid diagnostic signs because their scientific provenance, expert agreement, and inter-rater reliability were undocumented.

TABLE 2. Physical indicators preserved as archival inputs

Food category	Encoded physical indicators	Permitted interpretation
Fish	Pale gills; blood not fresh red; flesh recorded as not elastic; flies do not land	Unvalidated screening indicators
Tofu	Glossy appearance; unusually durable; elastic but not dense; excessively hard texture	Unvalidated screening indicators
Meatballs	Flies do not land; not sticky; durable beyond three days; not easily broken	Unvalidated screening indicators
Wet noodles	Unusually long shelf life; very elastic; not easily damaged; not sticky	Unvalidated screening indicators

Figure 1 defines the safety boundary used in the reconstruction. Every score remains a non-confirmatory screening output. Because no empirically validated threshold exists, the workflow does not assign “safe” or “positive” labels. Any decision requiring confirmation must be transferred to an authorized laboratory using a validated analytical method.

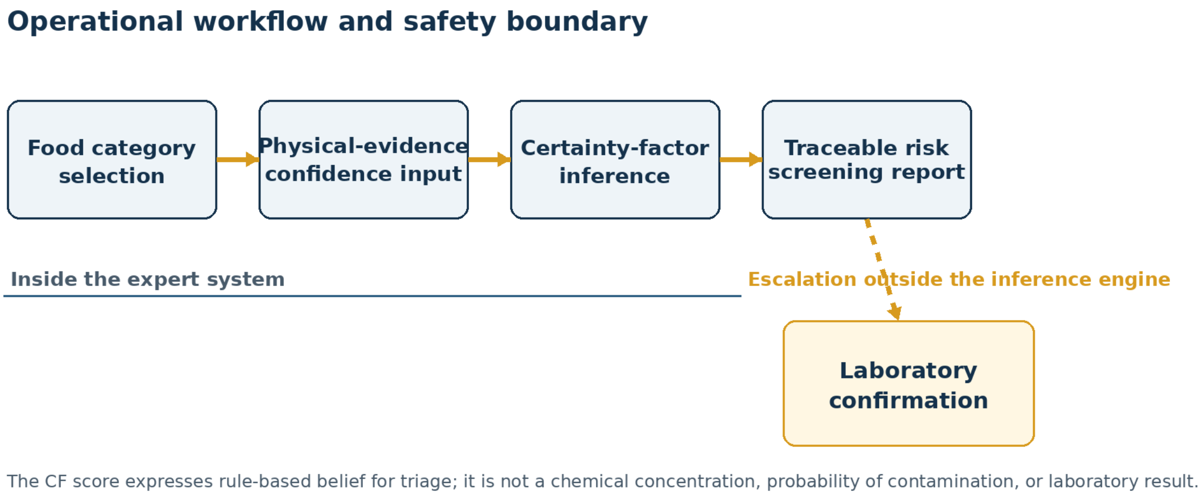

Fig. 1. Safety-aware screening workflow. Laboratory confirmation is outside the CF inference engine.

3.3. Certainty-Factor Reconstruction

For each positive evidence item E_i supporting hypothesis H, the reconstructed rule contribution c_i was calculated as the product of the archived expert weight and the user confidence value:

$$c_i = CFexpert(E_i) \times CFuser(E_i) \quad (1)$$

Two positive contributions were combined iteratively as follows:

$$CFnew = CFold + c_i(1 - CFold) \quad (2)$$

For valid contributions in the interval [0,1], repeated application is equivalent to $1 - \prod_i(1 - c_i)$. This identity provides an independent order-invariance check when no intermediate rounding is applied. The displayed percentage is $100 \times CFfinal$. The reconstruction does not extend the legacy method to negative CF values or contradictory evidence.

TABLE 3. User-confidence scale used for reproducible reconstruction

Response label	CF user	Operational meaning
Not observed	0.0	Explicitly recorded absence of positive evidence
Low confidence	0.2	Weakly observed or uncertain
Possible	0.4	Indicator may be present
Likely	0.6	Indicator is reasonably observed
Very likely	0.8	Indicator is strongly observed
Certain	1.0	Indicator recorded with maximal confidence

The labels in Table 3 are reconstruction labels applied to numeric inputs; they are not presented as a psychometrically validated observation scale. A missing response is invalid and is not silently converted to “not observed.” The archived expert weights are likewise treated as legacy rule weights of undocumented provenance.

3.4. Auditable Data Model

The proposed data model stores the rule version and a snapshot of every numeric input used in a consultation. This prevents later knowledge-base changes from altering the interpretation of a historical result. It also records the exact and rounded scores, calculation sequence, algorithm version, and laboratory-referral status. The model is a design specification for future implementation; it was not verified against the unavailable legacy database.

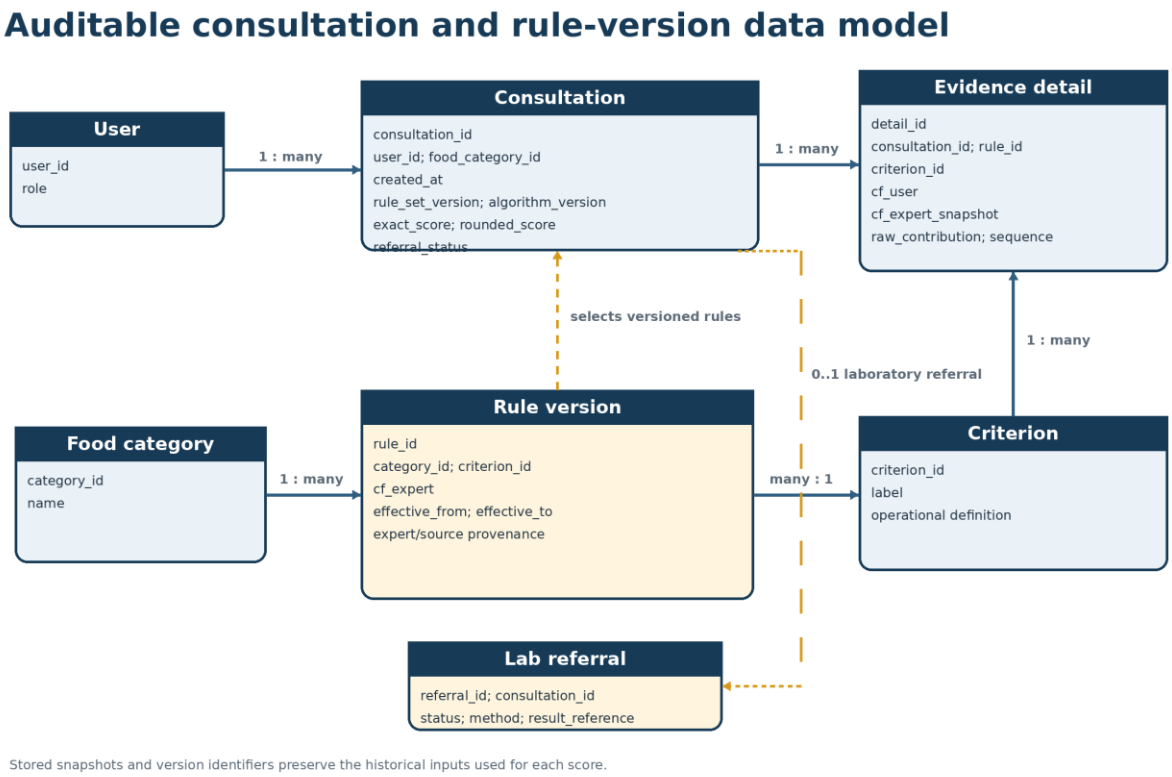

Fig. 2. Proposed versioned data model for reconstructable consultations and laboratory referral.

3.5. Evaluation Protocol

The evaluation comprised four checks. First, arithmetic reconstruction recalculated the fish score without using the displayed summary as an input. Second, cross-artifact coherence compared the reconstructed value with the available category-level summary and examined whether a matching detailed trace existed. Third, a deterministic verification suite tested mathematical boundaries, order invariance, missing values, and out-of-range inputs in an independent reference implementation. Fourth, a safety inspection examined whether the legacy interfaces contained actions or claims that conflicted with the laboratory-confirmation boundary.

Arithmetic acceptance required exact agreement between iterative aggregation and the closed-form identity before rounding. Summary agreement required equality at the displayed precision but was not treated as detailed trace verification. Invalid-input tests passed only when the reference procedure rejected missing, negative, or above-one values. The reconstructed reference procedure was:

```
INPUT: list of evidence contributions c[1..n]
IF any value is missing OR c[i] < 0 OR c[i] > 1: REJECT
score ← 0
FOR each c[i]: score ← score + c[i] × (1 − score)
RETURN exact score and round(100 × score) for display
```

4. RESULTS

4.1. Reconstructed Fish Scenario

The archived fish scenario contained four evidence contributions. Table 4 lists the expert and user values used in the independent reconstruction. These values reproduce the reported fish summary but are not supported by an available detailed fish trace from the interface.

TABLE 4. Inputs for the reconstructed fish screening scenario

Code	Physical evidence	CF expert	CF user	Contribution
E1	Pale gills	0.70	0.60	0.4200

Code	Physical evidence	CF expert	CF user	Contribution
E2	Blood not fresh red	0.50	0.80	0.4000
E3	Flesh recorded as not elastic	0.30	0.40	0.1200
E4	Flies do not land	0.70	0.40	0.2800

The cumulative values were $CF_{12} = 0.6520000$, $CF_{123} = 0.6937600$, and $CF_{1234} = 0.7795072$. The exact result was therefore 77.95072%, which rounds to 78%. The closed-form calculation, $1 - (1 - 0.42)(1 - 0.40)(1 - 0.12)(1 - 0.28)$, produced the same value.

TABLE 5. Arithmetic audit of iterative CF aggregation

Step	Old CF	New contribution	Exact cumulative CF	Displayed value
E1	—	0.4200	0.4200000	0.420
E1 + E2	0.4200	0.4000	0.6520000	0.652
+ E3	0.6520	0.1200	0.6937600	0.694
+ E4	0.69376	0.2800	0.7795072	0.780 / 78%

4.2. Cross-Artifact Coherence

The legacy category summary displayed "Ikan" (fish) at 78%, which agrees with the reconstructed result after rounding. However, the surviving detailed calculation screenshot concerned "Cumi" (squid), with contributions 0.42, 0.20, 0.24, and 0.42 and a summary of approximately 79.5%. It therefore cannot verify the fish calculation trace. The supported conclusion is limited to summary-level consistency between the independent fish reconstruction and the displayed fish percentage.

TABLE 6. Claims supported by the available evidence

Evaluation question	Available evidence	Supported conclusion
Is the reconstructed fish arithmetic internally consistent?	Iterative and closed-form calculations	Yes, for the archived numeric inputs
Does the fish summary display 78%?	Category-level legacy summary	Yes
Is a matching detailed fish trace available?	Detailed screenshot refers to squid, not fish	No
Does 78% indicate concentration or probability?	No chemical measurement or calibrated dataset	No
Can the system replace laboratory testing?	No validated specimen results	No

4.3. Deterministic Verification Suite

All valid test vectors produced identical results under iterative aggregation and the closed-form identity. The fish vector was invariant to reversal of contribution order when full precision was retained. Missing and out-of-range values were rejected rather than silently coerced. These results verify the reconstructed reference algorithm, not the unavailable legacy source code.

TABLE 7. Boundary and robustness tests for the reconstructed reference algorithm

Test	Contribution vector	Expected result	Observed result	Status
T1 Empty	[]	0.0000000	0.0000000	Pass
T2 Single	[0.42]	0.4200000	0.4200000	Pass
T3 All zero	[0, 0, 0, 0]	0.0000000	0.0000000	Pass

Test	Contribution vector	Expected result	Observed result	Status
T4 All one	[1, 1, 1, 1]	1.0000000	1.0000000	Pass
T5 Fish	[0.42, 0.40, 0.12, 0.28]	0.7795072	0.7795072	Pass
T6 Reversed fish	[0.28, 0.12, 0.40, 0.42]	0.7795072	0.7795072	Pass
T7 Missing	[0.42, 0.40, NA, 0.28]	Reject	Rejected	Pass
T8 Above range	[0.42, 1.20]	Reject	Rejected	Pass
T9 Negative	[-0.20, 0.40]	Reject	Rejected	Pass

The manual calculation and the prototype trace both yield 78% at the reported precision. This is evidence of arithmetic consistency for the single preserved scenario, not evidence of classification accuracy. Figure 3 consolidates the relevant interfaces: criterion management, food-category management, expert/user values, and the calculation trace. Login and generic dashboard images are omitted because they do not provide scientific evidence.

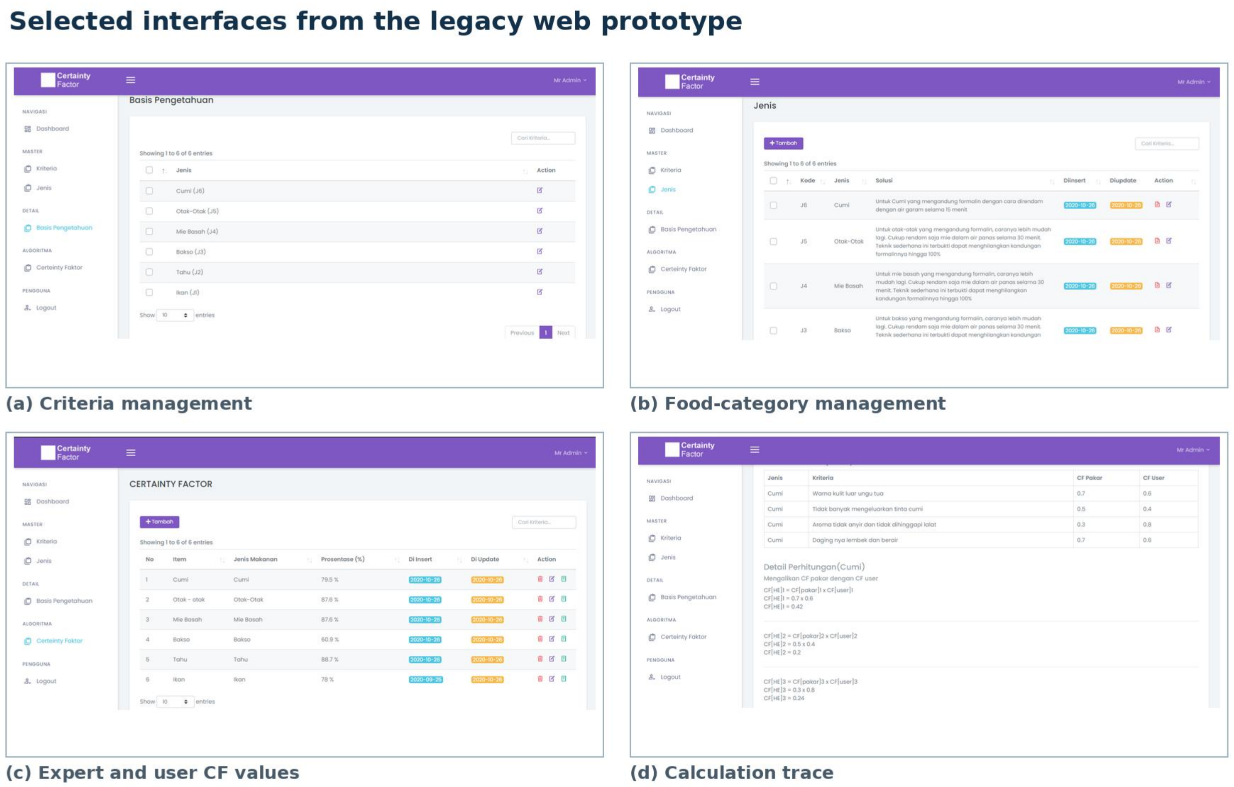

Fig. 3. Selected legacy prototype interfaces retained as implementation evidence

4.4. Safety and Structural Findings

The legacy interface included household-remediation text suggesting that soaking could remove formalin, including absolute effectiveness claims. Such advice was inconsistent with the evidentiary limits of the system and was excluded from the revised evidence presentation. Because the source code and deployment were unavailable, this audit cannot confirm that the unsafe function has been removed from any operational copy. Its removal, together with a persistent non-confirmation disclaimer and laboratory-referral instruction, is a mandatory precondition for future deployment.

The legacy artifacts also lacked sufficient information to reproduce historical consultations after rule changes. In particular, the provenance and effective dates of expert weights, snapshots of applied values, algorithm version, precise rounding policy, and referral records were absent or undocumented. Figure 2 addresses these deficiencies as a proposed implementation specification.

5. DISCUSSION

The audit establishes a narrower result than the original interpretation but a more defensible one. The fish values are arithmetically coherent and agree with the available category summary at the reported precision. This supports reconstruction of one score; it does not establish that formalin was present. Chemical determination requires validated analytical procedures that account for matrix behavior, selectivity, and measurement uncertainty [2]–[11].

The distinction between belief and accuracy is central. CF is a knowledge-representation mechanism derived from rule-based reasoning [17]. Its output depends on encoded weights and user confidence. Predictive accuracy instead requires labeled cases and an accepted reference standard. Kusnadi et al. [15] could report agreement because their evaluation used known meat samples. The present evidence contains no comparable laboratory-labeled dataset, so sensitivity, specificity, predictive values, calibration, and diagnostic accuracy cannot be estimated.

The cross-artifact check illustrates why interface screenshots should not be treated as interchangeable evidence. The available detailed trace belongs to a squid case, whereas the independently reconstructed scenario and summary concern fish. Reporting this mismatch prevents a summary-level match from being overstated as end-to-end verification. It also demonstrates the value of storing immutable input snapshots and rule versions for every consultation.

The safety inspection identified a more consequential legacy weakness: unsupported household remediation. A screening system must not authorize consumption, disposal, enforcement, or treatment decisions. Its interface should show the evidence trace, state that the score is non-confirmatory, and route suspected items to laboratory testing. When no threshold has been validated, the system should avoid categorical “safe” or “positive” labels and present referral as the only confirmatory pathway.

The proposed data model improves future auditability but remains unimplemented in the available evidence package. Before deployment, every rule should have documented expert provenance, effective dates, operational definitions, and inter-rater testing. Physical indicators—especially the archived fish criterion “not elastic,” which may conflict with descriptions of abnormal stiffness or firmness—require renewed domain-expert and laboratory evaluation rather than simple database preservation.

A prospective follow-up should collect blinded physical assessments and validated laboratory results for fish, tofu, meatballs, and wet noodles. It should report class balance, missingness, sensitivity, specificity, positive and negative predictive values, F1-score, calibration, and uncertainty intervals. At least one baseline, such as an unweighted rule score or logistic regression, should be included. External validation at a second site is required before public-health performance claims can be made.

6. CONCLUSION AND FUTURE WORK

This retrospective audit reconstructs a legacy certainty-factor calculation while separating what is demonstrable from what remains unavailable. The archived fish contributions combine to an exact score of 0.7795072, consistent with the prototype’s 78% fish summary after rounding. A matching detailed fish trace was not available; the surviving detailed trace pertains to squid. The result therefore demonstrates arithmetic and summary-level consistency only.

The audit also identifies unsafe remediation text, undocumented rule provenance, and insufficient transaction lineage. The proposed safety workflow and versioned data model address these weaknesses as requirements for future implementation, not as already deployed functions. Until the system is rebuilt, inspected, and validated against laboratory ground truth, every CF score must remain a non-confirmatory screening belief and must not be used to declare food safe or contaminated.

DECLARATIONS

Author Contributions

M.E.: Conceptualization, Methodology, Software, Investigation, Data Curation, Formal Analysis, Visualization, and Writing – Original Draft. **R.R.B.:** Validation, Formal Analysis, Supervision, and Writing – Review & Editing. **A.F.:** Software Verification, Data Curation, Visualization, and Writing – Review & Editing. All authors have read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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Ethical Approval and Informed Consent

This retrospective computational-artifact audit involved no new human participants, personal data, or biological specimen testing. Formal ethical approval and informed consent were therefore not applicable to the present audit. The provenance of historical expert-rule elicitation was unavailable and is reported as a limitation.

Data and Code Availability

All numerical inputs and deterministic test vectors required to reproduce the reported calculations are provided in Tables 4, 5, and 7 and in the reconstruction pseudocode. The institutional prototype source code and database export were not supplied with the evidence package and are therefore unavailable for independent software-level verification.

Conflicts of Interest

This research received no external funding.

Generative AI Use

A generative AI language assistant was used to support language editing, structural revision, and document preparation. It was not used to create laboratory data or to represent unavailable software evidence as observed results. The authors verified the calculations, references, interpretations, and final wording and remain responsible for the scientific content.

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