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FROM MANAGEMENT REVIEW TO SAFETY MARGIN CONTROL: A DECISION-TRACEABILITY MODEL FOR QUALITY AND SAFETY GOVERNANCE

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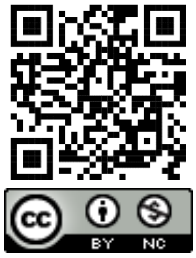

A B S T R A C T

Management review is a required element of many quality and safety management systems, yet it is often treated as a documentary compliance event rather than as an active governance control function. This study develops and applies a decision-traceability model for examining how senior review processes convert safety-relevant signals into decisions affecting safety margins. A qualitative and semi-quantitative dataset was constructed from nine public accident and incident cases across process safety, offshore energy, chemical manufacturing, rail, and maritime operations. The unit of analysis was the decision item, producing 45 coded items from official investigation reports, regulatory findings, and safety recommendations. Results show that 33 items (73.3%) reached traceability scores of 4 or 5, while 13 items (28.9%) displayed weak or incomplete conversion. Breakdowns concentrated in verification, diagnosis, and decision stages. The paper contributes a reproducible method for distinguishing documentary management review from effective safety governance.

1. INTRODUCTION

Quality and safety management systems depend on the ability of organizations to convert information into controlled action (Rane, 2023). Audits, incidents, nonconformities, operational deviations, performance indicators, and regulatory findings all generate signals about the state of a system (Nwachukwu et al., 2024). These signals, however, do not improve safety by their existence alone. They must be interpreted, escalated to the right level, converted into decisions, supported with resources, implemented through corrective or preventive action, and verified for effectiveness. The management review process sits at this conversion point. It is the formal or functional location where organizations decide whether detected information will change priorities, accountability, resources, operating limits, or safety margins (Rahman, 2025).

In many management-system contexts, management review is presented as a requirement for evaluating system performance, suitability, adequacy, and effectiveness. ISO 9001 and ISO 45001 both position review by top management as a mechanism for assessing the management system and identifying decisions and actions needed for improvement (International Organization for Standardization, 2015, 2018). In practice, however, review meetings and executive dashboards can become evidence of compliance rather than instruments of control. Minutes may record that information was presented, but not whether a decision was made. Action lists may show that tasks were assigned, but not whether resources were provided or effectiveness was verified. Corrective actions may be closed administratively without demonstrating that the underlying barrier or safety margin was restored (García & Rosique, 2024).

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This distinction is critical for high-hazard organizations. System safety engineering treats safety as an emergent property of controlled interactions rather than as a static attribute of components (Leveson, 2011). From this perspective, senior governance is not external to the technical system. It is part of the control structure that sets constraints, monitors feedback, allocates resources, accepts or rejects risk, and learns from degraded performance. When governance mechanisms do not transform signals into traceable decisions, the organization may continue to operate with degraded barriers while maintaining the appearance of a functioning management system (Wang et al., 2025).

The problem is not only that organizations miss weak signals. Major accident reports repeatedly show that signals were available before or after significant events: prior incidents, audit findings, known degradation mechanisms, abnormal operations, deferred maintenance, incomplete training, or repeated regulatory findings. The more specific governance question is whether those signals were converted into decisions with owners, resources, follow-up evidence, and effectiveness verification. A signal that is acknowledged but not escalated remains weak. A decision without ownership remains ambiguous. An action without verification remains open from a control perspective, even if it is closed administratively (Supriatna et al., 2025).

This article addresses the following research question: how do management review or equivalent senior governance processes convert safety-relevant signals into traceable decisions affecting safety margins? The article develops a decision-traceability model and applies it to 45 coded decision items drawn from nine public accident and incident cases. The objective is not to produce statistical generalization across all high-risk industries. The objective is to provide a reproducible analytical method for evaluating whether governance review functions as a safety control loop (Shekh, 2025).

The article makes three contributions. Conceptually, it reframes management review as a safety governance control loop that connects detection, diagnosis, decision, action, verification, and learning. Methodologically, it proposes the decision item as a unit of analysis and introduces two coding scales: a decision-traceability score and an evidence-quality rating. Empirically, it demonstrates the method on official public sources from process safety, offshore energy, chemical manufacturing, rail, and maritime cases. The article therefore bridges quality management, safety management systems, and system safety engineering by focusing on the missing link between information and decision.

2. THEORETICAL AND CONCEPTUAL BACKGROUND

2.1 Management review in quality and safety management systems

Management review has an established role in quality management. In the quality tradition, management responsibility is linked to policy, objectives, resources, measurement, and continual improvement. Deming's management philosophy emphasized that improvement depends on leadership decisions about systems, not only on inspection or worker-level correction (Deming, 1986). Modern quality management systems extend this logic by requiring leadership to review system performance, identify improvement opportunities, and ensure that the management system remains aligned with organizational needs (International Organization for Standardization, 2015).

Occupational health and safety management systems extend this review logic into the domain of hazards, risk controls, worker participation, legal compliance, incidents, and improvement actions (International Organization for Standardization, 2018). Yet the management-system literature often gives more operational attention to audits, nonconformity handling, and corrective-action closure than to the decision quality of management review itself. Review is frequently described as a periodic process, whereas the critical safety question is functional: did the review convert evidence into control action (McKinnon, 2025)?

The distinction matters because a management review record can be formally complete while remaining weak as a decision-control artifact. It may list inputs, show attendance, and state that performance was reviewed. These features document occurrence, not necessarily governance effectiveness. A stronger review artifact would show the signal considered, the risk interpretation, the decision taken, the owner, the resources or authority granted, the target date, the follow-up evidence, and the criteria used to verify effectiveness. This chain is what the present article calls decision traceability (Tuladhar et al., 2024).

2.2 Safety governance and senior management responsibility

Safety governance refers to the way senior leaders set priorities, allocate authority, monitor critical risks, and ensure that safety constraints remain effective under production pressure. Accident research has long shown that disasters are not reducible to front-line error. They emerge from interactions among technical systems, management decisions, regulatory oversight, resource constraints, and organizational assumptions (Perrow, 1999; Reason, 1997; Rasmussen, 1997). Senior management therefore acts as a control layer. It influences the margins within which operational actors must work.

This governance role is visible in official investigations of major industrial events. The BP Texas City case involved repeated warning signals, process-safety weaknesses, and recommendations aimed at board-level oversight and process-safety indicators (U.S. Chemical Safety and Hazard Investigation Board, 2007; 2014; 2015). The Macondo investigation emphasized major hazards, safety-critical elements, SEMS, verification, and governance responsibilities (U.S. Chemical Safety

and Hazard Investigation Board, 2016; 2017; 2018; 2022). Lac-Megantic and El Faro similarly show that regulatory oversight, SMS implementation, audit closure, and senior operational support can influence whether weak signals become effective controls (National Transportation Safety Board, 2017; Transportation Safety Board of Canada, 2014).

Senior responsibility is not satisfied by awareness alone. Governance requires a decision architecture. A board, executive committee, safety committee, regulator, or delegated management body must determine which signals require escalation, which decisions require formal risk acceptance, which actions need resources, and which outcomes must be verified. Without this architecture, accountability becomes dispersed. The organization may know about a hazard but lack a traceable decision path showing what was done with that knowledge.

2.3 Control loops, feedback, and safety margins

A control-loop view clarifies the role of management review. In a controlled system, a controller receives feedback about the system state, compares it with a goal or constraint, and issues control actions intended to keep the process within acceptable boundaries. In safety, these boundaries can be understood as constraints or safety margins. Degradation occurs when barriers are weakened, operational variation increases, warning signals are normalized, or corrective action is delayed. System safety engineering therefore focuses on constraints, feedback quality, authority, and the ability to correct deviations before losses occur (Leveson, 2011).

Safety margins are not only technical. They are also organizational. A margin may depend on inspection intervals, staffing levels, competence, management of change, emergency planning, maintenance backlog, technical review, and the willingness to stop or modify work. A governance review that allocates resources to a degraded barrier can restore a margin. A review that defers action without justification can erode it. A review that closes an action without checking effectiveness can create a false impression that the margin has been restored.

Traditional feedback models in quality management emphasize measurement, review, action, and improvement. For high-risk organizations, the same logic must be connected to hazards and barriers. A process-safety indicator, for example, is not valuable simply because it appears on a dashboard. It is valuable if it triggers diagnosis, decision, resource allocation, action, and verification when it reveals degraded control. This is why decision traceability is central to the present model. It makes the feedback loop auditable.

2.4 Decision traceability as a missing link in safety governance

Decision traceability is defined here as the degree to which a public or internal record connects a safety-relevant signal to a review mechanism, a decision, an owner, resources or authority, follow-up action, effectiveness verification, and an effect on safety margins. It does not require that all decisions be positive. A traceable decision may accept a risk, defer an action, or reject a recommendation, provided that the rationale, authority, and follow-up are visible. What matters is that the decision path is reconstructable.

This concept helps distinguish compliance from control. Compliance asks whether a required review occurred. Control asks whether the review changed the system in response to feedback. Compliance asks whether an action was closed. Control asks whether closure restored the barrier. Compliance asks whether a dashboard exists. Control asks whether the dashboard changed a decision. The decision-traceability model therefore creates an analytical bridge between quality management documentation and system safety engineering.

The model is also compatible with accident investigation. Official reports often contain recommendations, responses, closure statuses, audit findings, risk assessments, and organizational analyses. These materials can be coded as decision items. A decision item may be a positive conversion, such as a recommendation that leads to a verified governance change. It may also be a failure to convert, such as a repeated signal that did not trigger escalation, an audit closure without effectiveness verification, or a decision with no identifiable owner.

3. CONCEPTUAL MODEL: MANAGEMENT REVIEW AS A SAFETY GOVERNANCE CONTROL LOOP

The conceptual model treats management review as a safety governance control loop. The term management review is used functionally rather than narrowly. It includes formal reviews required by quality or safety management standards, but also board safety oversight, executive safety reviews, safety governance committees, corrective-action review, management-of-change review, regulatory oversight decisions, safety recommendation tracking, and senior operational support. These mechanisms are equivalent when they perform the same control function: converting feedback about risk into decisions that affect constraints, barriers, or safety margins.

The model contains six stages. The first stage is detection of safety-relevant signals. Signals include audit findings, nonconformities, incidents, recommendations, known degradation mechanisms, abnormal operations, weak indicators, or changes in external conditions. The second stage is diagnosis and prioritization. At this stage, the organization interprets the signal, connects it to hazards and barriers, and determines whether senior escalation is required. The third stage is senior governance decision. A decision can authorize action, require analysis, allocate resources, revise a standard, accept risk, stop work, or defer action. The fourth stage assigns responsibility and resources. A decision without ownership or authority remains weak. The fifth stage is corrective or preventive

action. The sixth stage is follow-up, effectiveness verification, and learning.

The model also identifies the places where conversion fails. A signal may not become a decision. A decision may have no owner. An owner may receive no resources. An action may be completed without effectiveness verification. A recurrent issue may not be escalated. An indicator may be measured but not used for governance. A management review may therefore exist as a documented event while the control loop remains open. Figure 1 presents the control-loop model, and Figure 2 presents the signal-to-decision traceability pathway used to code the dataset.

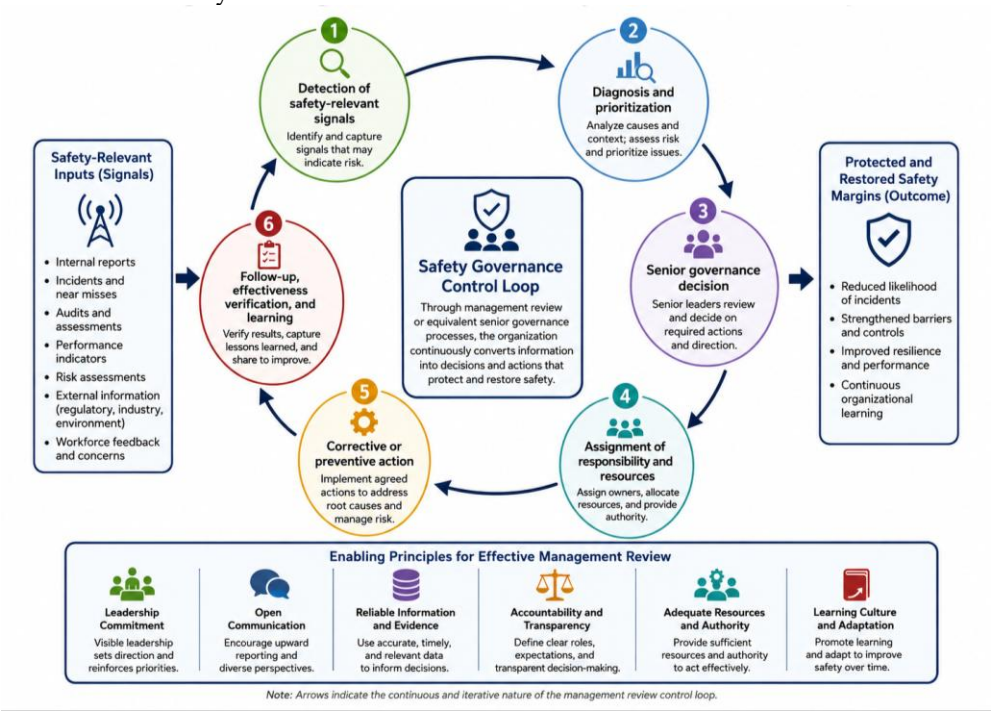

Figure 1. Management review as a safety governance control loop

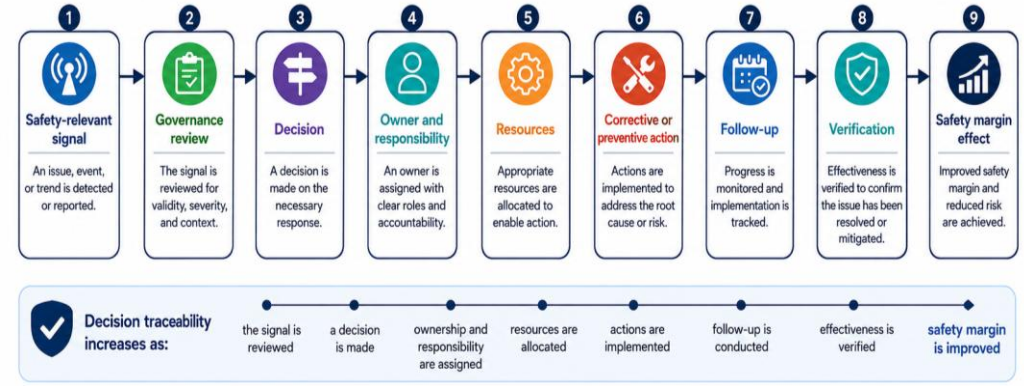

Figure 2. Signal-to-decision traceability pathway

4. METHODOLOGY

The study uses a qualitative and semi-quantitative multiple-case design. Public accident and incident cases were selected because official reports provide visible traces of safety signals, governance weaknesses, corrective actions, and recommendations. The purpose was not to estimate the frequency of governance failure in a population of organizations. The purpose was to construct and test a reproducible coding method for evaluating the conversion of safety information into governance decisions.

The empirical dataset includes nine cases: BP Texas City, Macondo/Deepwater Horizon, Chevron Richmond, Tesoro Anacortes, ExxonMobil Torrance, Husky Superior, Arkema Crosby, Lac-Megantic, and El Faro. These cases were selected across process safety, offshore energy, chemical manufacturing, rail, and maritime operations. They were included only when official public sources contained enough information to identify a safety-relevant signal, a management-review equivalent, a decision or failure to decide, and a plausible connection to a barrier or safety margin. Famous cases were not included merely because they were well known; they were included because the public record contained codable decision-traceability evidence.

The primary sources were official accident investigation reports, regulatory reports, public investigation materials, and safety recommendations. The U.S. Chemical Safety and Hazard Investigation Board provided the main public source for the process-safety and offshore cases; the Transportation Safety Board of Canada provided the primary source for Lac-Megantic; and the National Transportation Safety Board provided the primary source for El Faro. Peer-reviewed and conceptual sources were used only to frame the model, not as primary evidence for decision items.

The unit of analysis was the decision item. A decision item is a codable element of governance: a decision, non-decision, weak decision, assignment, resource decision, corrective action, closure status, or verification failure associated with a safety-relevant signal. This unit was chosen because accidents and organizations are too coarse for examining management review. A single case can contain multiple governance conversions and multiple breakdown points. The final dataset contains 45 decision items, with five items coded for each case.

Each decision item was coded for signal type, signal source, hazard or risk, affected barrier, governance level, management-review equivalent, decision status, decision type, decision owner, resource allocation, action type, follow-up evidence, effectiveness verification, safety-margin effect, feedback-loop stage, conversion-failure type, and evidence quality. The codebook was designed to be transparent enough for replication and sufficiently compact for use in quality and safety governance research.

Two scales structure the analysis. The decision-traceability score ranges from 0 to 5: 0 indicates no traceable review or decision; 1 indicates that a signal was acknowledged only; 2 indicates that a decision was mentioned without an owner or deadline; 3 indicates a decision with owner or action but weak follow-up; 4 indicates a decision with action and follow-up evidence; and 5 indicates full closed-loop traceability, including signal, decision, owner, action, follow-up, and effectiveness verification. The evidence-quality rating also ranges from 1 to 5, from contextual evidence only to public evidence of signal, decision, responsibility, action, follow-up, and effectiveness verification.

Coding was based on explicit sections, recommendation numbers, findings, or report chapters when available. When page numbers were not available in the dataset, the source section, recommendation, or report element was retained. The analysis distinguishes direct evidence from analytical inference. For example, a recommendation with a public closure status was treated as stronger evidence than a general finding of weak management oversight. Items requiring inference were retained only when the public source connected the signal to a decision, action, or barrier in a manner sufficient for transparent coding.

Table 1. Case register and sectoral distribution

ID	Case	Sector	Jurisdiction	Year	Body	Evidence	Items
C01	BP Texas City Refinery Explosion	Process safety / refining	United States	2005	CSB	5	5
C02	Macondo / Deepwater Horizon Blowout	Offshore energy	United States / Gulf of Mexico	2010	CSB	5	5
C03	Chevron Richmond Refinery Fire	Process safety / refining	United States	2012	CSB	5	5
C04	Tesoro Anacortes Refinery Fatal Explosion	Process safety / refining	United States	2010	CSB	5	5
C05	ExxonMobil Torrance Refinery Explosion	Process safety / refining	United States	2015	CSB	5	5
C06	Husky Superior Refinery Explosion	Process safety / refining	United States	2018	CSB	5	5
C07	Arkema Crosby Chemical Plant Fire	Chemical manufacturing	United States	2017	CSB	4	5
C08	Lac-Mégantic Rail Disaster	Rail / dangerous goods transport	Canada	2013	TSB Canada	5	5
C09	SS El Faro Sinking	Maritime	United States / Bahamas area	2015	NTSB	5	5

Table 2. Decision-traceability coding framework

Coding group	Variables	Analytical purpose	Output
Input signal	signal_type; signal_source; hazard_or_risk	Identifies the evidence entering the governance loop.	Links audits, incidents, indicators, findings, and recommendations to a codable decision item.
Control target	affected_barrier; safety_margin_effect	Identifies the barrier or margin affected.	Connects decision traceability to system-safety controls rather than generic compliance.
Governance process	governance_level; management_review_equivalent; decision_status	Identifies the review mechanism and whether a decision was made.	Distinguishes review, escalation, acceptance, closure, and non-decision.
Decision resources	decision_type; decision_owner; resource_allocation; action_type	Documents assignment and commitment.	Separates documentary acknowledgement from traceable governance action.
Closure evidence	follow_up_evidence; effectiveness_verification	Documents follow-up and whether closure was verified.	Tests whether the loop was actually closed.
Analytical scoring	decision_traceability_score; feedback_loop_stage; conversion_failure_type; evidence_quality	Transforms qualitative evidence into comparable codes.	Supports cross-case and semi-quantitative analysis.

5. RESULTS

5.1 Case distribution and empirical scope

Table 1 summarizes the empirical scope. The dataset contains nine cases and 45 decision items. Process safety and refining account for 25 items, reflecting the availability of detailed CSB recommendation and closure records in refinery investigations. Offshore energy, chemical manufacturing, rail, and maritime operations each contribute five items. This distribution was not intended to represent industry frequency. It reflects source richness for decision-traceability coding.

The case register also shows differences in the type of governance evidence available (Table 2). CSB cases often contain recommendations with explicit addressees and closure statuses, which support higher traceability and evidence-quality ratings. Lac-Megantic and El Faro contain rich evidence of SMS and oversight weaknesses, but the relevant decision paths often show missing escalation, incomplete verification, or weak ownership. These differences are analytically useful because the dataset contains both positive post-event closed-loop conversions and incomplete governance loops identified in accident analysis.

5.2 Distribution of decision traceability scores

The mean decision-traceability score across the 45 items was 3.96. No item was scored 0. Five items (11.1%) were scored 1, four items (8.9%) were scored 2, three items (6.7%) were scored 3, nine items (20.0%) were scored 4, and 24 items (53.3%) were scored 5. Thus, 33 items (73.3%) reached scores of 4 or 5, indicating action with follow-up evidence or full closed-loop traceability. This high proportion reflects the inclusion of public recommendations and closure information, especially in CSB cases (Table 3, Figure 3).

The low-score items are nonetheless central to the article's argument. They show that the traceability model can identify weak governance conversion even when a management system or oversight process formally exists. Lac-Megantic contains items coded as signal without decision, action without verification, recurrent issue without escalation, and decision without ownership. El Faro contains items coded as signal without decision and action without verification, alongside later recommendations for SMS revision and operational support. These cases show how management review can be present as a regulatory or organizational expectation while failing to function as an effective control loop.

Table 3. Distribution of decision traceability scores.

Score	Definition	Count	Percentage
0	No traceable review or decision	0	0.0%
1	Signal acknowledged only	5	11.1%
2	Decision mentioned but no owner or deadline	4	8.9%
3	Decision with owner or action but weak follow-up	3	6.7%
4	Decision with action and follow-up evidence	9	20.0%
5	Full closed-loop traceability	24	53.3%

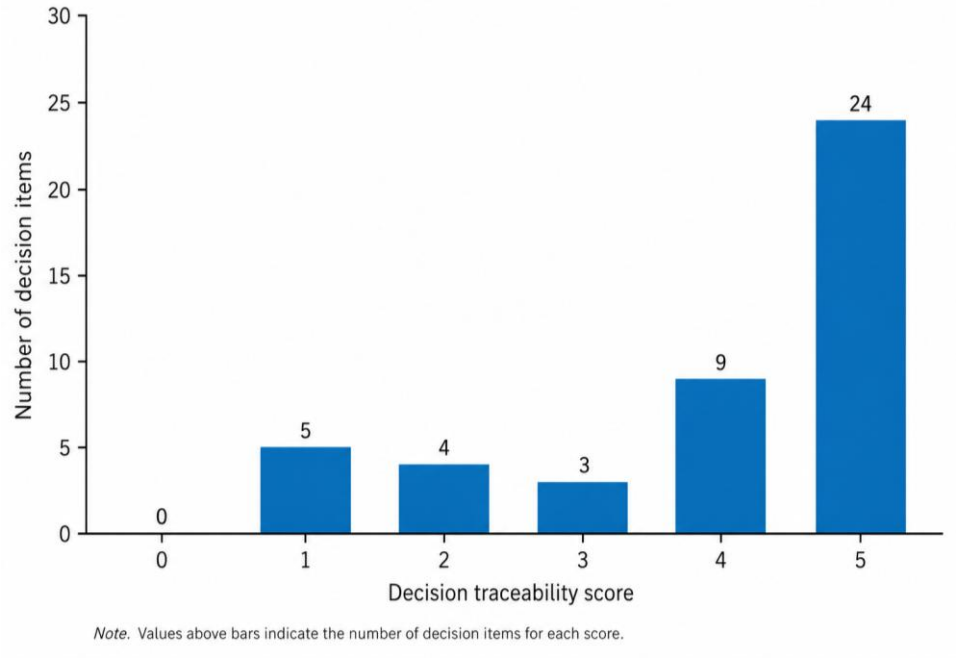

Figure 3. Distribution of decision traceability scores

5.3 Evidence quality across cases

Evidence quality was generally strong. Thirty-two items (71.1%) were rated 5, eleven items (24.4%) were rated 4, and two items (4.4%) were rated 3. No decision item was rated below 3. This was an intentional inclusion decision. Items with only contextual evidence were excluded from the core dataset because they would not support a publishable decision-traceability analysis. High evidence quality does not mean that every decision was effective before the event. It means that the public source contained enough evidence to support transparent coding of the signal, governance mechanism, decision or non-decision, and follow-up status.

Table 4 compares cases by average traceability and average evidence quality. Chevron Richmond, Husky Superior, ExxonMobil Torrance, BP Texas City, and Macondo show high average traceability because their decision items are closely linked to official recommendations, technical review, corrective actions, and closure evidence. Lac-Megantic and El Faro show lower average traceability because the coded items emphasize breakdowns in risk assessment, SMS implementation, audit closure, shoreside support, and regulatory oversight. Their evidence quality remains high because the official reports document those weaknesses clearly.

Table 4. Evidence quality and average traceability by case

ID	Case	Items	Avg. traceability	Avg. evidence	Principal pattern
C01	BP Texas City Refinery Explosion	5	4.60	4.60	closed-loop governance
C02	Macondo / Deepwater Horizon Blowout	5	4.40	4.60	closed-loop governance
C03	Chevron Richmond Refinery Fire	5	5.00	5.00	closed-loop governance
C04	Tesoro Anacortes Refinery Fatal Explosion	5	4.20	4.60	closed-loop governance
C05	ExxonMobil Torrance Refinery Explosion	5	4.60	4.60	closed-loop governance
C06	Husky Superior Refinery Explosion	5	4.80	4.80	closed-loop governance
C07	Arkema Crosby Chemical Plant Fire	5	4.20	4.20	closed-loop governance
C08	Lac-Mégantic Rail Disaster	5	1.40	5.00	action without verification
C09	SS El Faro Sinking	5	2.40	4.60	signal without decision

5.4 Main conversion failure types

The most common pattern was closed-loop governance, which appeared in 32 items (71.1%) (Table 5). This category indicates that the public record connected a safety signal to a decision, owner or responsible body, action, and follow-up evidence. The remaining 13 items (28.9%) were weak or incomplete conversion patterns. Action without verification occurred four times (8.9%), signal without decision occurred three times (6.7%), decision without resources occurred twice (4.4%), and one item each was coded as decision without ownership, recurrent issue without escalation, weak indicator use, and not enough evidence.

These patterns show that the weakest points are not limited to the initial detection of safety signals. Many breakdowns occur after a signal is known. Action without verification means that the organization or oversight body moved beyond awareness but did not provide evidence that the action restored the relevant barrier. Decision without resources indicates that a governance decision was visible but the resource commitment was not. Signal without decision indicates a more severe conversion failure: the public record shows a safety-relevant signal but no traceable governance decision sufficient to control the risk.

Table 5. Conversion failure types across decision items

Conversion failure type	Count	Percentage	Interpretation
closed-loop governance	32	71.1%	positive conversion pattern
action without verification	4	8.9%	weak or incomplete conversion pattern
signal without decision	3	6.7%	weak or incomplete conversion pattern
decision without resources	2	4.4%	weak or incomplete conversion pattern
not enough evidence	1	2.2%	weak or incomplete conversion pattern
weak indicator use	1	2.2%	weak or incomplete conversion pattern
recurrent issue without escalation	1	2.2%	weak or incomplete conversion pattern
decision without ownership	1	2.2%	weak or incomplete conversion pattern

5.5 Feedback-loop stages where traceability breaks down

Across all 45 decision items, the most frequently coded feedback-loop stages were verification (13 items), learning (11 items), decision (9 items), diagnosis (6 items), action (4 items), and detection (2 items) (Figure 4). When only weak or failure items are considered, the concentration changes. Verification accounts for four weak items, decision and diagnosis each account for three, detection accounts for two, and learning accounts for one. These results suggest that the control loop often breaks after the organization has already become aware of a signal.

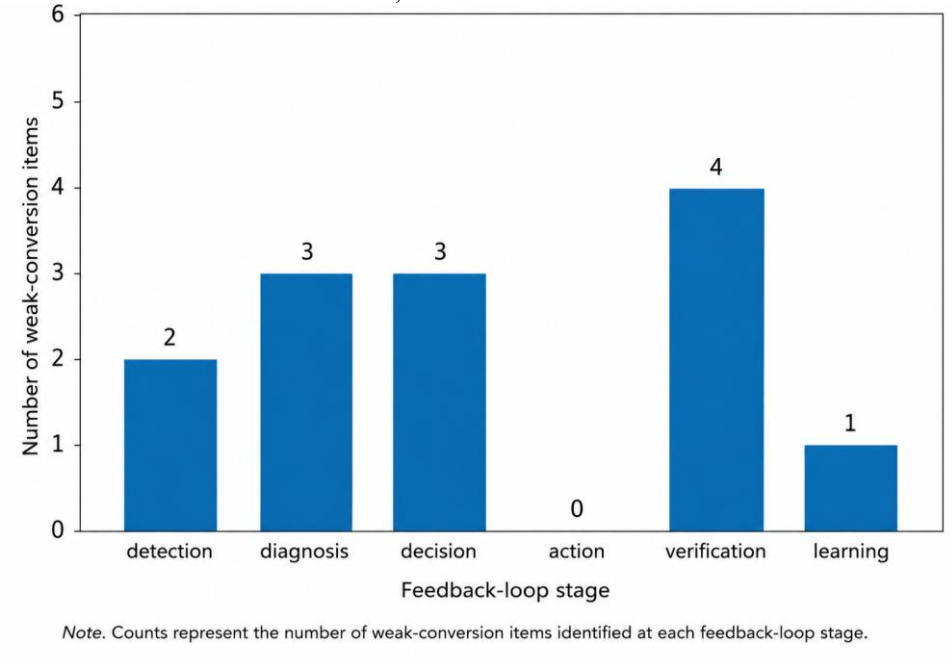

Figure 4. Conversion failures by feedback-loop stage

This finding has practical significance for management review. A review agenda focused only on whether issues were raised may miss the main failure mode. The more important questions are whether the issue was diagnosed correctly, whether a decision was taken at the right level, whether resources and ownership were assigned, and whether effectiveness was verified. Verification is especially important because administrative closure can mask residual risk. From a system-safety perspective, the loop is not closed until the affected barrier or safety margin is demonstrably restored or revised.

5.6 Cross-sector patterns

The sectoral pattern reflects both empirical reality and source availability. Process safety and refining cases provided the largest number of high-traceability items because CSB investigations frequently produce detailed technical and organizational recommendations. Offshore energy provided codable items concerning safety-critical elements, SEMS, major-hazard reporting, and regulatory verification. Chemical manufacturing contributed items on extreme-weather risk, common-mode safeguard failure, process-safety information, and corporate policy. Rail and maritime cases contributed the strongest examples of incomplete governance conversion: risk assessment, SMS audit closure, headquarters oversight, shoreside support, and weather routing.

The cross-sector comparison shows that decision traceability is not sector-specific. The same governance questions apply across industries: what signal was reviewed, what barrier was affected, who made the decision, what resources were assigned, what action was taken, and how effectiveness was verified? The terminology differs across industries, but the control problem is structurally similar. This is why a quality and safety governance framework can use accident investigation evidence from multiple sectors without reducing the analysis to a single regulatory regime.

5.7 Examples of closed-loop governance and incomplete governance loops

BP Texas City illustrates post-event closed-loop governance in several decision items. The dataset includes items on the independent safety panel, board process-safety expertise, incident-learning systems, process-safety indicators, and operational control decisions. These items show how a repeated set of process-safety signals can be converted into board-level review, reporting structures, indicator governance, and corrective-action tracking. They also show the limitation of post-event closure evidence: a strong traceability score after the accident does not mean that the organization had effective management review before the accident.

Macondo illustrates the governance of safety-critical elements. Decision items address standards for safety-critical elements, BOP control barriers, SEMS governance, regulatory assurance, and major-hazard documentation. Chevron Richmond illustrates the conversion of technical degradation signals into damage-mechanism hazard review, deferred-work authorization, technical approval, and safety-culture oversight. By contrast, Lac-Megantic and El Faro illustrate incomplete loops. In both cases, SMS or equivalent oversight processes existed, but the coded items show signals that were not converted into effective risk decisions, verified corrective actions, or clear ownership.

6. DISCUSSION

6.1 Management review as a conversion mechanism

The results support the central argument that management review is best understood as a conversion mechanism. It receives safety-relevant information and should convert that information into decisions that preserve or restore safety margins. This reframing changes the object of analysis. Instead of asking whether management review occurred, the analyst asks what happened to the signal. Was it diagnosed? Was it escalated? Was a decision made? Was an owner assigned? Were resources allocated? Was effectiveness verified?

This conversion view is consistent with quality management, but it is more demanding than documentary compliance. Continual improvement requires more than periodic review. It requires an auditable path from evidence to action. For high-hazard systems, this path must be connected to barriers and margins. A review that recognizes a problem but does not assign responsibility is an incomplete control action. A review that assigns an action but does not verify effectiveness is an open loop. A review that accepts degraded conditions without visible rationale may normalize erosion.

6.2 Why safety signals fail to become safety decisions

The weak conversion patterns in the dataset suggest four recurrent mechanisms. First, signals may be interpreted as operational issues rather than governance issues. In such cases, senior management may not see the need to make or record a decision. Second, decisions may be framed as technical or procedural tasks without explicit ownership. Third, resource implications may remain hidden. A recommendation may require staffing, training, engineering change, or inspection capacity, but the decision record may not show whether those resources were allocated. Fourth, action closure may focus on task completion rather than effectiveness verification.

These mechanisms are not mutually exclusive. A recurrent audit finding may remain at the local level because it is viewed as a compliance issue rather than a barrier-degradation signal. A safety indicator may be reviewed but not linked to risk acceptance or resource allocation. A corrective action may be closed because a procedure was revised, even though the underlying control was not tested under operating conditions. The

decision-traceability model makes these differences visible.

6.3 Decision traceability and safety margins

Safety margins provide the system-safety link between management review and accident prevention. A margin is reduced when barriers degrade, inspection intervals lengthen without adequate justification, maintenance is deferred, staff are insufficient for safe operations, hazard analyses are incomplete, or emergency planning does not reflect foreseeable conditions. A management review can restore a margin by authorizing repair, redesign, training, shutdown, revised procedures, more conservative limits, or independent verification. It can also erode a margin by deferring action, accepting risk without analysis, or closing actions without evidence.

The dataset shows that safety-margin effects can be coded from public evidence when the report connects a decision item to a barrier. Examples include process-safety oversight, safety-critical equipment, damage-mechanism review, safeguard requirements, extreme-weather protection, SMS audit closure, and operational support. The margin concept prevents the analysis from becoming purely administrative. It asks whether governance altered the constraints under which the system operated.

6.4 Implications for quality management and safety governance

For quality management, the study suggests that management review should be evaluated as a process with outputs that are traceable, risk-informed, and verifiable. Review inputs are important, but the quality of outputs matters more. A mature management review record should show how evidence was filtered, prioritized, and translated into decisions. It should also show why some signals were not escalated or why certain risks were accepted. This is particularly relevant for integrated management systems, where quality, safety, reliability, environmental, and operational performance indicators compete for attention.

For safety governance, the model creates a practical audit lens. Boards and executives can ask whether each significant safety signal has a decision trail. Regulators can examine whether oversight findings led to verified corrective action rather than administrative closure. Accident investigators can use the pathway to distinguish detection failures from conversion failures. Internal auditors can use the score to evaluate not only whether management review was performed, but whether it functioned as a control loop.

6.5 Implications for auditors, regulators, and senior managers

Auditors should treat management review minutes, dashboards, action registers, and closure records as evidence of a decision-control process. The relevant audit question is not simply whether the organization reviewed incidents or indicators. It is whether the organization can show a traceable path from signal to decision to verified effect. This shifts audit attention toward ownership, resource decisions, escalation, effectiveness criteria, and evidence of barrier restoration.

Regulators can use the same logic when assessing corrective-action plans. A plan that identifies an action but lacks an owner, resource commitment, deadline, or verification method should be treated as weak. A repeated finding that remains closed and reopened without escalation should be treated as a governance signal. Senior managers can use the model to structure review agendas. Each significant signal should be discussed in terms of affected barrier, safety-margin effect, decision required, responsible owner, resources, target date, verification method, and learning outcome.

6.6 Contribution to system safety engineering

The contribution to system safety engineering is to place senior governance inside the control structure. System safety work often focuses on hazard analysis, barriers, requirements, and technical controls. These are essential, but they depend on management decisions for resources, authority, prioritization, and revision. A safety requirement that is not reviewed when evidence changes can become obsolete. A barrier that is monitored but not repaired when degraded cannot function as intended. A corrective action that is closed without verification cannot provide assurance.

By making the decision item the unit of analysis, the model provides a bridge between accident investigation evidence and management-system improvement. It allows researchers to code governance behavior without requiring access to confidential board minutes. It also allows practitioners to design better review records. A management review record should not merely demonstrate that management looked at information. It should demonstrate that the organization controlled the system in response to information.

7. PRACTICAL IMPLICATIONS

The model can be used as a practical checklist for senior managers, quality managers, safety managers, auditors, regulators, and accident investigators. Senior managers can use it to structure review agendas around decision requirements rather than information presentation. Quality managers can use it to strengthen the output side of management review by linking inputs to owners, resources, actions, and verification criteria. Safety managers can use it to connect indicators, incident learning, nonconformities, and hazard-review results to barrier restoration.

Auditors can use the decision-traceability score as a diagnostic tool. A score of 1 or 2 suggests that the organization is documenting awareness but not control. A score of 3 indicates partial conversion but weak

follow-up. A score of 4 indicates that action and follow-up evidence exist, while a score of 5 indicates full closed-loop traceability. This scoring should not become a mechanical rating exercise. Its main value is to guide questions about evidence, authority, resources, and effectiveness.

Regulators and accident investigators can use the model to examine whether corrective actions have been closed prematurely. If a safety recommendation is closed because a procedure was issued, but no evidence shows that the procedure changed behavior or restored a barrier, the loop remains incomplete. Similarly, if an audit finding is repeatedly closed and reappears, the issue should be escalated from nonconformity handling to governance review. The practical aim is to prevent review processes from becoming repositories of information that do not change system constraints.

8. LIMITATIONS

The study has limitations. First, it relies on public sources. Public accident reports and recommendation databases provide valuable evidence, but they do not contain all internal deliberations, board discussions, risk-acceptance rationales, or resource-allocation records. The absence of visible evidence in the public record is therefore not necessarily evidence that no internal decision occurred. The coding should be interpreted as public decision traceability, not complete organizational reality.

Second, the cases are heterogeneous. CSB reports, TSB reports, and NTSB reports differ in structure, scope, recommendation tracking, and level of detail. CSB cases often support higher traceability ratings because recommendation closure information is visible. Transportation cases may document pre-event governance weakness in great detail but provide less item-level closure evidence. This heterogeneity is a limitation but also a finding: public visibility of decision traceability varies across sectors and investigation regimes.

Third, the dataset was coded by a single analytical process. Future research should test inter-coder reliability, refine the category boundaries, and apply the codebook to internal management review records where confidentiality allows. Fourth, the analysis does not claim statistical generalizability. The dataset was designed for model development and analytical demonstration. Its value lies in making governance conversion visible and reproducible, not in estimating prevalence rates.

9. CONCLUSION

This article developed and applied a decision-traceability model for analyzing management review as a safety governance control loop. The model reframes management review from a compliance event to a control function that should convert safety-relevant signals into traceable decisions, responsibilities, resources, actions, verification, and learning. The empirical application used 45 decision items from nine public accident and incident cases across five high-risk sectors.

The results show that public investigation sources can support robust coding of governance decision items. They also show that weak conversion often occurs after signals are already known. The most important failures are not always detection failures. They include decisions without resources, actions without verification, recurrent issues without escalation, and signals without traceable decisions. These patterns are central to distinguishing documentary compliance from effective safety governance.

The contribution is conceptual, methodological, and practical. Conceptually, the article connects quality management review to system safety control theory. Methodologically, it proposes the decision item and the decision-traceability score as tools for analyzing governance evidence. Practically, it offers a review logic that can be used by managers, auditors, regulators, and investigators to test whether safety information changes the system. Future research should apply the model to internal management review records, compare sectors, and validate the codebook with multiple coders.

Data availability statement

The dataset generated and analyzed during the current study is available in a view-only Open Science Framework repository titled Management Review Decision-Traceability Dataset: https://osf.io/54xkm/overview?view_only=8b078296f1aa4420993ae080bdd95db0 . The repository includes the case register, decision-item coding table, codebook, scoring rules, evidence-quality scale, references, and supplementary methodological materials.

Conflict of interest statement

The author declares no conflict of interest.

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