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RESEARCH ARTICLE

Towards Health-Promoting Occupational Health and Safety in Aluminium Smelter Feasibility Planning: A Macroergonomic Case Study

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ABSTRACT

Introduction: Aluminium smelter feasibility studies must address not only technical and economic viability but also the early design of a safe socio-technical work system. This study evaluated how occupational safety, process safety, human factors, contractor interfaces, and operational readiness were integrated into one aluminium smelter feasibility study.

Methods: An evaluative qualitative case study combined a structured document review, literature- and standards-based benchmarks, and semi-structured interviews with four purposively selected experts. Each analytical indicator was classified as present, partially operationalized, or absent. The judgment was derived from explicit evidence requirements, document content, interview convergence or contradiction, and relevance to feasibility-stage decisions. NVivo supported data organization and auditability but coding frequency was not used as evidence of thematic importance.

Results: The document contained conventional feasibility components and generic safety provisions. However, most macroergonomic dimensions were only partially operationalized. Competence planning, occupational hygiene, organizational arrangements, and process safety were mentioned but lacked defined requirements, deliverables, responsibilities, or verification criteria. Human-machine interface evaluation, contractor interface governance, major-accident analysis, and operational-readiness gates were absent or insufficiently specified. Expert evidence converged on six priority gaps: competency assurance, HMI and control-room risk, HAZOP/PHA and major-accident scenarios, contractor interfaces, occupational hygiene baselines, and operational readiness.

Conclusion: This single-case study does not establish a general model for all aluminium smelter projects. Its contribution is a case-based evaluative framework that makes macroergonomic judgments traceable through explicit indicators and evidence thresholds. The framework can support identification of feasibility-stage gaps that may otherwise be transferred to engineering, commissioning, and operations, but its predictive value requires testing in additional projects and longitudinal settings.

Keywords: Macroergonomics; Feasibility Study; Aluminium Smelter; Occupational Safety and Health; Process Safety; Work System

INTRODUCTION

Aluminium smelter development represents a complex industrial investment requiring technical, financial, legal, environmental, organizational, and operational appraisal. Classical feasibility guidance emphasizes commercial, technical, financial, economic, and environmental prerequisites before an investment decision is made (1). Contemporary feasibility research further connects project appraisal with governance, risk, implementation conditions, and decision-relevant non-financial factors (2,3). For high-risk industrial projects, feasibility analysis should therefore provide an early basis for deciding whether the proposed system can be engineered, constructed, commissioned, and operated safely. From an occupational health-promotion perspective, feasibility-stage decisions can provide an upstream opportunity to strengthen the prevention of occupational injury and disease and to support the development of a healthy and safe workplace.

Occupational safety and process safety must be considered together in process industries. Risk-based process safety requires hazard understanding, operational discipline, asset integrity, emergency preparedness, and management systems that control major-accident risk (4,5). Human error should not be interpreted solely as individual failure because latent organizational conditions, poorly designed interfaces, workload, competence gaps, and inadequate system support shape human performance (6,7). Decisions made during feasibility can consequently create risk pathways that remain hidden until detailed engineering, commissioning, or operation.

Macroergonomics provides a suitable analytical lens because it evaluates the joint design of people, tasks, technology, organization, and work environment as a socio-technical system (8-11). Safety climate, design-for-safety, task analysis, and systems-oriented ergonomics have been linked to safer behavior and to the prevention of risk inheritance from early project decisions (12-18). The aluminium-smelting context adds high-temperature processes, molten metal, dust, fume, gas, noise, electricity, mobile equipment, ergonomic demands, and potential major-accident scenarios (9,19-21).

Previous research leaves three linked gaps. First, feasibility-study and project-appraisal literature describes technical, economic, environmental, governance, and implementation-readiness domains, but rarely specifies document-level indicators for judging whether a high-risk project has translated human and safety considerations into traceable feasibility commitments. Second, process-safety literature provides mature expectations for hazard analysis, barriers, asset integrity, and pre-startup readiness, but generally addresses management-system or design-stage implementation rather than how those expectations should be represented at the feasibility decision gate. Third, macroergonomics explains joint optimization of people, organization, technology, tasks, and environment, yet has seldom been operationalized as an auditable framework for reviewing an industrial feasibility document. Consequently, the unresolved question is not simply whether safety topics are mentioned, but whether feasibility-stage evidence is sufficiently connected and actionable to guide later engineering and readiness decisions. This study addresses that gap by applying an explicit evidence-threshold framework to one aluminium-smelter feasibility document and using expert interviews to explain the significance, boundaries, and downstream implications of the observed document patterns. The contribution is therefore an empirically illustrated, case-based set of analytical indicators rather than a universal model or a prevalence estimate.

Conceptual Boundaries and Analytical Framework

The analysis distinguished four related but non-equivalent domains. Occupational safety concerns personal injury and health risks arising from work activities and exposures. Process safety concerns loss of containment, fire, explosion, uncontrolled energy, and other low-frequency–high-consequence events requiring engineered and organizational barriers. Human factors engineering concerns the design of tasks, interfaces, controls, alarms, workload, and human–machine function allocation to support reliable performance. Macroergonomics operates at the higher work-system level: it evaluates whether human, organizational, technological, task, environmental, and external-interface conditions are jointly designed and coordinated. In this study, occupational safety, process safety, and human factors were treated as substantive domains; macroergonomics was the integrative lens used to assess their relationships with organization, competence, contractors, and operational readiness. An item was therefore not classified as macroergonomically integrated merely because it appeared under a safety or human-resources heading; integration required an explicit relationship to other work-system elements and a traceable feasibility-stage commitment.

METHODS

Research Design

This study used an evaluative qualitative case-study design. The case was one feasibility study document for an aluminium smelter construction project at PT XYZ. The design was appropriate because the objective was not statistical generalization but a structured assessment of how a bounded project document addressed predefined and emergent socio-technical safety issues. The unit of analysis was the feasibility study document, while expert interviews were used to challenge, clarify, and contextualize the document-based judgments.

Data Sources and Informants

Data comprised: (1) the feasibility study document; (2) theoretical, technical, and regulatory references on feasibility, occupational safety, process safety, macroergonomics, human factors, and non-ferrous industries; and (3) four semi-structured expert interviews. Maximum-variation purposive selection was used to obtain complementary perspectives across operations/commissioning, project and contractor HSE, occupational hygiene, and systems-oriented OHS. Eligibility required more than 10 years of relevant experience and direct involvement in smelter or comparable high-risk process settings. The aim was not demographic representation or statistical saturation, but sufficient information power for a narrow case, specific informants, theory-guided dialogue, and an in-depth analytical strategy (22). Each interview followed the same core guide with tailored probes and lasted approximately 30 to 40 minutes. Recruitment stopped at four because the interviews supplied complementary expertise and no additional core dimension was identified in the fourth interview; this was treated as information adequacy, not as proof that all possible views had been exhausted.

Table 1. Anonymous expert profiles and analytical contribution

Code	Professional background and experience	Primary analytical contribution
I1	More than 14 years in operations, commissioning, and technical review in integrated steel and petrochemical process industries.	Operational readiness, fire protection, HAZOP, human factors, HMI/control-room risk, operability, and maintainability.
I2	More than 25 years in HSE for steel/smelter projects from construction through operation.	Construction-operation interfaces, explosion and fire risk, workforce and organization, contractor safety, and field implementation.
I3	More than 14 years in work environment and industrial hygiene in steel/smelter settings.	Multi-hazard exposure, occupational hygiene baseline, competence, CSMS, maintenance, and worker/community protection.
I4	More than 12 years in OHS for smelter and other high-risk process industries.	Safety by design, compliance, fatigue management, HAZOP, contractor governance, human-machine allocation, and operational readiness.

Source: Primary data synthesis

Evaluation Framework and Evidence Threshold

Three review instruments were integrated into one analytical framework. The first assessed conventional feasibility conformity; the second assessed occupational- and process-safety content; and the third assessed macroergonomic integration. Items were derived before final gap synthesis from the cited feasibility guidance, ISO 21502, ISO 6385, process-safety references, human-factors and macroergonomics literature, and non-ferrous-industry guidance (1-9) (11,19,23). The instruments were used as structured qualitative rubrics rather than additive psychometric scales. Each item was judged against the same evidence thresholds present, partially operationalized, or absent and the overall judgment for a dimension followed the weakest material requirement rule: a dimension could not be classified as present when a critical feasibility-stage element such as ownership, deliverable, hazard linkage, interface, or verification criterion was missing.

Table 2. Summary of the three document-review instruments and judgement logic

Instrument	Primary dimensions	Principal sources	Unit of judgement	Role in synthesis
Feasibility conformity	Project rationale; alternatives; technology; resources; organization; implementation; risk; environment; operational readiness	UNIDO and project-appraisal guidance; ISO 21502; project-risk literature	Whether each expected domain was identifiable and translated into a feasibility assumption, requirement, or deliverable	Established whether the document performed a conventional and implementation-oriented feasibility function
Occupational and process safety	Worker hazards and exposures; prevention and protection; major-accident scenarios; PHA/HAZOP strategy; fire/explosion basis; emergency planning; safety-critical barriers	ILO/OSHA non-ferrous guidance; CCPS; process-risk and OHS literature	Whether hazard-specific requirements, responsible parties, staged studies, and verification expectations were defined	Distinguished generic safety statements from actionable personal- and process-safety commitments
Macroergonomic integration	People/competence; organization; tasks/work design; technology/HMI; environment/hygiene; contractor interfaces; operational readiness; cross-system relationships	Hendrick and Kleiner; ISO 6385; socio-technical and systems-safety literature	Whether elements were connected through dependencies, interfaces, trade-offs, ownership, deliverables, and transition criteria	Identified relational gaps that would not be visible through topic-presence checking alone
Cross-instrument synthesis	Convergence, contradiction, negative evidence, and downstream significance	Document evidence plus expert interviews	Final judgment based on documentary traceability first; interviews interpreted significance but did not substitute for missing document evidence	Produced the case-based gap statement and phase-transfer mechanisms

Table 3. Classification logic for document-review judgements

Classification	Minimum evidence requirement	Interpretive rule
Present	The issue is explicitly described, linked to a relevant hazard or work-system decision, and translated into a defined requirement, responsibility, deliverable, or verification criterion.	The document provides sufficient feasibility-stage direction for later engineering or implementation.
Partially operationalized	The issue is mentioned or a generic control is proposed, but one or more critical elements are missing: hazard linkage, system interaction, responsibility, deliverable, resource basis, or verification criterion.	The document recognizes the issue but does not make it actionable or auditable.
Absent	No explicit evidence was found, or the content was too indirect to support a defensible feasibility-stage requirement.	The issue cannot be traced to a document commitment or transition requirement.

Source: Primary data synthesis

Data Collection and Analysis

The analytical pathway contained seven traceable stages. First, the three theory-informed instruments were finalized and a codebook defined each dimension, inclusion rule, exclusion rule, and evidence threshold. Second, feasibility-document passages were extracted with section/page identifiers and mapped to checklist items. Third, each item was classified as present, partially operationalized, or absent, with a short memo recording the evidence and missing requirement. Fourth, interview transcripts were familiarized and segmented into meaning units. Fifth, deductive codes based on the framework and inductive codes arising from informant explanations were applied, compared, refined, and grouped into categories and themes. Sixth, matrix coding was used only to retrieve convergence, divergence, and informant-specific emphasis; numerical frequencies were not used to rank theme importance. Seventh, document judgments and interview explanations were integrated in a gap-synthesis matrix that recorded: benchmark expectation, documentary evidence, classification, supporting or contradictory interview evidence, alternative interpretation, and possible downstream mechanism. This sequence preserved the feasibility document as the primary object of evaluation while using interviews to interpret significance rather than to replace absent documentary evidence.

Interviews were analyzed using deductive-inductive thematic analysis (24,25). Deductive codes represented feasibility, occupational safety, process safety, competence, organization, technology, work environment, contractor interfaces, and readiness. Inductive codes captured issues not sufficiently represented in the preliminary framework, including abnormal-condition competence, HMI simulation, fatigue assumptions, owner–contractor interfaces, and transition-gate readiness. A theme was retained when it was relevant to the research question, supported by sufficiently rich explanatory material, and connected to a document-review judgment; occurrence across all four informants was neither necessary nor sufficient. Contradictory or narrower views were retained in analytical memos instead of being forced into consensus.

Representative excerpts were translated into English and lightly condensed without changing their substantive meaning. Excerpts were selected for explanatory depth, specificity to the feasibility stage, relation to a documentary finding, and capacity to show convergence or divergence. The reporting and selection of excerpts also followed established qualitative quality criteria (26).

Trustworthiness and Bias Reduction

Confirmation bias was reduced through the use of predefined evaluation criteria before final interpretation; separation of the document review from the expert interviews; non-disclosure of the confidential feasibility document and preliminary document-review findings to informants; active searches for negative or disconfirming evidence; retention of contradictory interview statements; memoing of researcher assumptions; and maintenance of an audit trail linking source passages, codes, classifications, and final claims. Because the researcher had professional occupational safety and health experience, reflexive notes were maintained throughout the analysis to distinguish prior professional expectations from evidence identified in the case. These procedures were used to strengthen credibility, dependability, confirmability, and transparency of the qualitative judgments.

Ethical Considerations

Ethical approval for this study was obtained from the Research Ethics Committee of the Faculty of Public Health, Universitas Indonesia Number: Ket-502/UN2.F10.ETK/PPM.00.02/2026. Before participation, each informant received an explanation of the study purpose, interview procedures, voluntary nature of participation, confidentiality protections, and the right to decline or withdraw without penalty. Written informed consent was obtained before the interviews and included permission to audio-record and use anonymized quotations in academic publications. Formal permission to review and use the internal feasibility study document for academic research was obtained from the authorized company representative. The document was not shared with the informants, and no proprietary technical, commercial, organizational, or personally identifying information is reported. The company and informants were assigned anonymized identifiers, and only non-identifying professional profiles are presented. Digital files, transcripts, consent records, and analytical materials were stored in password-protected and access-restricted storage available only to the research team; direct identifiers were kept separately from the analytical dataset. All data were used solely for the approved academic purposes.

RESULTS

Overall Document Assessment

The feasibility study fulfilled its conventional pre-investment function. It described the project, capacity, process technology, utilities, construction and operation plans, investment, environmental aspects, risk, and a safety plan. The critical finding was not a total absence of safety-related content. Rather, the document frequently recognized an issue without converting it into a defined feasibility-stage requirement. This pattern produced a large middle category of partially operationalized content and explains the use of the term partial integration.

Table 4. Evidence-based comparison of document content and macroergonomic expectations

Dimension	Robust feasibility-stage expectation	Evidence identified in the document	Classification	Triangulated analytical judgment
Human resources and competence	Role-specific competency requirements, certification basis, staffing assumptions, abnormal-condition competence, technology-transfer plan, and training deliverables.	Human resources and general training needs were identified, but no competency assurance architecture, abnormal-condition criteria, or HMI/OTS training requirement was specified.	Partially operationalized	I1 and I4 emphasized readiness for abnormal conditions and technology-human interaction; I3 linked competence to multi-hazard exposure. The gap concerns assurance and verification, not complete omission.
Organization and work management	Operating organization, HSE/process-safety accountability, decision rights, shift design, fatigue controls, safety performance indicators, and interfaces across functions.	Organization and management arrangements were mentioned, but process-safety ownership, fatigue assumptions, decision rights, and cross-functional interfaces were not sufficiently defined.	Partially operationalized	Experts described organization as a risk-control system. Fragmented accountability may delay decisions and normalize unresolved design or readiness issues.
Technology, HMI, and work-system design	Human-machine function allocation, control-room/HMI requirements, alarm philosophy, workload considerations, operability, maintainability, and human-factors design reviews.	Process technology and equipment were described, but no explicit HMI, control-room human-factors, function-allocation, or workload evaluation was found.	Absent	I1 and I4 linked HMI and control-room design to human error, abnormal-situation detection, operability, and maintainability. Equipment selection alone did not demonstrate socio-technical assessment.
Occupational and process safety	Hazard register, PHA/HAZOP strategy, major-accident scenarios, safety-critical barriers, fire/explosion basis, emergency scenarios, and transition to later design studies.	Generic hazard identification, fire protection, safety measures, and risk-control planning were present; PHA/HAZOP scope, major-accident scenario basis, and barrier verification were not operationalized.	Partially operationalized	I4 explicitly identified HAZOP as relevant from planning and design. I2 and I3 highlighted smelter fire, explosion, gas, dust, and other major-hazard characteristics.
Work environment and occupational hygiene	Baseline exposure assumptions for heat, dust, fume, gas, noise, radiation, ergonomics, ventilation, monitoring, and linkage to staffing and technology.	Environmental and worker-protection measures were included, but no integrated occupational-hygiene baseline, exposure characterization plan, or design acceptance criteria were identified.	Partially operationalized	I3 framed smelting as a multi-hazard environment and emphasized baseline exposure information. The gap was the absence of a design-linked hygiene strategy.
Contractor safety and owner-contractor interfaces	Contractor risk segmentation, CSMS expectations, competence requirements, interface responsibilities, communication, simultaneous-operations controls, and procurement deliverables.	General construction safety was discussed, but CSMS, interface governance, contractor competence criteria, and owner-contractor risk allocation were not explicit.	Absent	I2 gave the strongest contractor emphasis, while I3 and I4 also identified CSMS and interface risk. Deferral to procurement or construction leaves feasibility assumptions untested.

Dimension	Robust feasibility-stage expectation	Evidence identified in the document	Classification	Triangulated analytical judgment
Operational readiness	Readiness criteria for people, procedures, asset integrity, emergency capability, maintenance, spare parts, PSSR, knowledge transfer, and handover gates.	An operation plan was present, but no integrated readiness framework, readiness owner, acceptance criteria, or pre-startup gate was specified.	Absent	I1, I3, and I4 described readiness as multidimensional rather than merely a production start date. The document did not show how safe transition to operation would be demonstrated.
Macroergonomic integration	Explicit analysis of interactions among people, organization, technology, task, environment, contractors, and safety across project phases.	Relevant elements appeared in separate sections but were not synthesized as interacting work-system conditions.	Partially operationalized	The integration gap was relational: dispersed content did not show dependencies, trade-offs, interface risks, or coordinated deliverables.

Source: Primary data synthesis.

Interview Evidence and Analytical Convergence

The interviews did not establish significance through frequency. Their analytical contribution was to explain why a documentary omission or weak operationalization could matter, to test whether the predefined indicators were meaningful in practice, and to identify plausible alternative interpretations. For example, several informants considered detailed HAZOP, final HMI specifications, or complete staffing arrangements to belong to later engineering stages. The resulting interpretation was therefore not that feasibility studies must contain final design detail, but that they should define the required study, owner, timing, interface, acceptance basis, and transition gate. Representative evidence is summarized in Table 5.

Table 5. Representative interview evidence linked to specific claims

Issue	Representative evidence	Analytical use
Competence and abnormal conditions	I1/I4: Operator readiness should be demonstrated for normal and abnormal situations; training should include interaction with the HMI and realistic operating scenarios.	Supports the distinction between generic training content and a verifiable competency-assurance system.
HMI and control-room risk	I1: "The human-machine interface is also important because the system needs to be designed to help control potential human error."	Provides direct evidence that HMI design was viewed as a system-level barrier against human error, supporting the classification of absent human-factors integration.
HAZOP/PHA and major hazards	I4: HAZOP is relevant to identify process hazards from planning and design. I3 characterized the smelter as a major-hazard setting involving gas, dust, noise, explosion, and radiation.	Links the need for a defined PHA strategy and scenario basis to the smelter hazard profile.
Contractor interfaces	I2: "There is a risk of disrupted communication between the owner, who holds extensive information about the feasibility study and its risks, and the contractor carrying out the work in the field."	Provides direct evidence that owner-contractor information transfer is a critical risk interface, supporting the classification of contractor governance as absent.
Occupational hygiene	I3: Feasibility assessment should establish the expected exposure profile and controls for workers and surrounding communities, including environmental and emergency readiness.	Supports the need for baseline exposure assumptions and design acceptance criteria.
Operational readiness	I3: "The feasibility study needs to explain project readiness from several aspects: the production process, occupational safety and health for workers and surrounding communities, the environment, infrastructure and utilities, and emergency preparedness."	Provides direct evidence that readiness is multidimensional and extends beyond a production start date, supporting the need for an integrated readiness gate.

Source: Primary data synthesis

Cross-Phase Risk Mechanism

The results indicate that fragmentation creates risk through interfaces rather than through isolated missing items. A competence plan that is not linked to HMI design may produce operators who are trained but unable to manage interface complexity. A PHA requirement without defined ownership or transition gates may be delayed until detailed engineering, when design options are more constrained. Occupational-hygiene assumptions that are not connected to ventilation, staffing, shift patterns, and maintenance can result in controls that are technically installed but operationally ineffective. Contractor requirements deferred to procurement may create unclear responsibility and inconsistent risk acceptance during construction and commissioning.

Table 6. Mechanisms by which feasibility-stage fragmentation may transfer risk

Feasibility-stage fragmentation	Likely downstream mechanism	Potential phase affected
HMI not linked to competence and abnormal scenarios	Late interface redesign, weak situational awareness, inconsistent response to abnormal conditions.	Detailed engineering, commissioning, operation
PHA/major-accident analysis not defined as a staged deliverable	Hazards identified after key layout or technology decisions; barriers added rather than designed in.	Engineering and construction
Occupational hygiene not linked to design assumptions	Ventilation, enclosure, monitoring, and staffing controls developed without a common exposure basis.	Engineering and operation
Contractor governance not included in feasibility requirements	Risk responsibilities and competence standards negotiated late or inconsistently.	Procurement, construction, shutdowns
Operational readiness treated as schedule rather than assurance gate	Startup proceeds with incomplete procedures, training, maintenance, emergency capability, or handover evidence.	Commissioning and startup

Source: Primary data synthesis.

DISCUSSION

This study shows that the analytical value of macroergonomics lies in evaluating relationships, not merely counting safety topics. The feasibility document contained many relevant elements, but their separation across technical, organizational, environmental, and safety sections obscured dependencies among people, technology, tasks, organization, and environment. Macroergonomics and socio-technical systems theory predict that system performance emerges from these interactions (8-11). Consequently, a document may appear comprehensive at item level while remaining weak at system level. In this context, the relevance to occupational health promotion is primarily preventive and system-oriented: feasibility-stage decisions can establish conditions that support the prevention of occupational injury and disease and a healthy and safe workplace.

The explicit three-level classification addresses an important interpretive problem. “Present” was reserved for content that was actionable and traceable; “partially operationalized” was used when an issue was acknowledged but lacked linkage, ownership, deliverables, or verification; and “absent” indicated no defensible feasibility-stage requirement. This distinction prevents a generic safety statement from being treated as equivalent to a defined PHA strategy, competency-assurance process, occupational-hygiene baseline, or readiness gate. It also clarifies why the dominant finding was partial rather than complete non-integration.

The process-safety findings demonstrate that generic hazard identification and fire protection do not substitute for staged process-hazard analysis. Risk-based process safety requires systematic hazard understanding, barrier management, operational discipline, and lifecycle governance (4,5). HAZOP and related PHA approaches are valuable because they test deviations from design intent and reveal interactions that may not be visible in generic risk lists (4). At feasibility stage, the expected output is not necessarily a fully detailed final HAZOP, but a defined hazard-analysis strategy, major-accident basis, responsible parties, input requirements, and transition criteria for later studies.

Competence and HMI findings further show why human factors cannot be postponed until training. Human error theory indicates that performance is shaped by system conditions (6,7). If control philosophy, alarms, function allocation, workload, maintainability, and abnormal-situation scenarios are not considered when technology choices are made, later training may only compensate for design limitations. This supports design-for-safety and human-centered systems research showing that early decisions influence downstream risk and the feasibility of reliable work (12,13,27-29).

Occupational hygiene must likewise be integrated with design and organization. Aluminium and other non-ferrous processes involve heat, dust, fume, gas, noise, chemical and physical exposures (19,23). A baseline does more than list hazards: it establishes assumptions that inform ventilation, enclosure, monitoring, staffing, shift design, maintenance, and emergency arrangements. Without these links, occupational-hygiene controls may remain generic and difficult to verify.

Contractor safety and operational readiness reveal two critical lifecycle interfaces. Contractor activities are part of the project work system, so competence, communication, risk allocation, simultaneous operations, and owner-contractor decision rights should be specified before procurement and mobilization. Operational readiness is similarly a cross-functional assurance process involving people, procedures, assets, maintenance, emergency response, knowledge transfer, and handover. Design-to-construction research likewise shows that risks can be transferred across project phases when responsibilities and controls are not established early (30). Treating readiness as a schedule milestone rather than an evidence-based gate may allow unresolved feasibility assumptions to pass into startup.

Alternative explanations must be considered. The observed fragmentation may partly reflect document genre, confidentiality, or project-stage conventions rather than managerial neglect: detailed HAZOP worksheets, HMI specifications, exposure models, or contractor procedures may legitimately reside in separate engineering packages. In addition, a feasibility study may rely on organizational standards not reproduced in the document. These possibilities weaken any claim that the project itself lacked safety capability. However, they do not remove the document-level finding. When a feasibility study does not identify the required downstream study, responsible owner, acceptance basis, and decision gate, reviewers cannot determine whether the omitted detail is intentionally deferred or simply unplanned. The evaluative concern is therefore traceability across phases, not maximal technical detail within the feasibility report.

Embedding macroergonomic indicators at the feasibility stage also has practical constraints. An excessively detailed checklist could duplicate basic engineering, impose costs before technology selection stabilizes, or create false assurance through administrative completion. A proportionate approach is therefore required. Feasibility-stage indicators should focus on decision-relevant assumptions and minimum commitments: critical hazards and exposure profiles; organizational and competence assumptions; human–technology interface risks; required later studies; accountabilities; resources; and hold points for engineering, procurement, commissioning, and startup. The proposed indicators should function as a screening and governance framework, not as a substitute for HAZOP, detailed human-factors engineering, occupational-hygiene assessment, CSMS implementation, or PSSR.

The scientific contribution is deliberately bounded. The study does not demonstrate the prevalence of macroergonomic gaps across aluminium projects, validate a universal scoring scale, or establish a causal effect on incident outcomes. It provides an empirically illustrated evaluative framework showing how topic presence can be separated from operationalization and relational integration at a feasibility decision gate. Its additional knowledge lies in the explicit document-level indicators, the evidence-threshold logic, and the phase-transfer mechanisms generated from the convergence and tension between one feasibility document and four complementary expert perspectives. These propositions are analytically transferable for testing in other high-risk project cases, but require external validation, inter-rater testing, and prospective study before wider standardization.

Limitations

The study assessed one confidential feasibility document and four expert interviews. The findings are analytically rather than statistically generalizable and may reflect the project stage, document-authoring convention, organizational standards, and accessibility of supporting documents. The experts did not review the case document, which reduced confirmation bias and protected confidentiality but limited their ability to challenge case-specific interpretations. Information adequacy was judged through information power and thematic completeness within the narrow scope, not through population saturation. The review was conducted by the researcher and did not include independent double-rating or formal inter-rater agreement; consequently, the three-level judgments remain interpretive despite explicit criteria and an audit trail. Translated and condensed excerpts may also lose some linguistic nuance. No field observation, engineering-package review, longitudinal follow-up, or safety-performance data were available. The proposed indicators therefore require testing across multiple projects, project stages, document types, and reviewers, including assessment of feasibility, reliability, and predictive usefulness.

CONCLUSION

In this single aluminium-smelter case, the feasibility document contained conventional project-appraisal and generic safety content, but several work-system dimensions were not traceably operationalized. The evidence supported three distinctions: some requirements were present and actionable; others acknowledged relevant issues without specifying ownership, deliverables, interfaces, or verification; and several human-factors, contractor-interface, and operational-readiness requirements were absent from the reviewed document. The case therefore supports a bounded analytical proposition: feasibility reviews can be strengthened by testing not only whether safety and human factors are mentioned, but whether they are connected to hazards, work-system interactions, responsible parties, downstream studies, and transition criteria. The resulting case-based indicators are intended as a screening and governance aid and do not replace detailed engineering or prove that their use will prevent incidents. Multi-case and prospective validation is required before they can be proposed as a general aluminium-smelter feasibility framework. Accordingly, feasibility planning may also serve as an upstream opportunity to strengthen occupational health promotion by making requirements for injury and disease prevention, worker protection, and a healthy and safe workplace more traceable before later project phases.

DECLARATIONS

Author contributions: AUA contributed to conceptualization, data collection, document review, interview analysis, NVivo-assisted coding, thematic synthesis, and manuscript drafting. HD contributed to supervision, methodological review, occupational safety and health interpretation, process safety interpretation, and critical revision of the manuscript. All authors reviewed and approved the final manuscript.

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