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Diagnosing Operational Waste and Barriers to Material-Value Retention in Project-Based Welding: An Integrated VSM-PAM and Thematic Analysis Approach

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Abstract

Project-based welding combines variable work content, parallel component flows, and interdependent quality-control activities, making it difficult to diagnose operational waste and barriers to material-value retention simultaneously. This exploratory single-case study applied an integrated current-state framework combining Value Stream Mapping (VSM), Process Activity Mapping (PAM), eight-waste identification, and NVivo-assisted thematic analysis to a rolling-stock welding value stream. Data were collected through direct observation, a gemba walk, and semi-structured interviews with four production and quality-control personnel. The current-state VSM recorded a total lead time of 609,358 s (169.27 h), comprising 324,867 s (90.24 h) of processing and 284,491 s (79.03 h) of waiting. PAM provisionally classified 53.21% of lead time as value-adding, 0.10% as necessary non-value-adding, and 46.69% as non-value-adding waiting. All eight lean wastes were identified. Thematic analysis generated 138 coding references across ten subthemes and five principal themes. The most prominent factors concerned welding-standard and sequence compliance, inspection and quality control, resource readiness, coordination and information exchange, and operator competence and discipline. Circularity-related evidence emerged from scrap segregation, potential reuse of residual materials, and efficient use of production resources. The integrated findings indicate that waiting, work-in-process accumulation, over-welding, defects, and rework arise from interconnected process, quality, resource-readiness, human, and organizational conditions. The study presents an integrated qualitative diagnosis that links operational waste to barriers to retaining material value in project-based welding.

1. Introduction

Manufacturing companies are increasingly required to improve operational efficiency while reducing resource consumption and retaining material value within production systems [1], [2], [3]. These requirements reflect two interrelated challenges. The first concerns operational waste, including waiting, unnecessary transportation and motion, excess work-in-process, overprocessing, defects, and rework[4]. The second concerns material-value loss resulting from excessive processing, rejected components, residual scrap, and the limited reuse of recoverable materials [5]. Improving production flow alone may reduce processing time without necessarily addressing material losses [6]. Conversely, concentrating exclusively on material recovery may overlook the operational conditions that initially generate those losses [7], [8]. These interdependencies indicate the need for an integrated Lean-Circular perspective that examines operational waste and material-value retention as connected production issues.

Lean manufacturing seeks to create customer value by eliminating or reducing activities that consume time, labor, materials, equipment, and space without contributing to product requirements [9], [10], [11]. The eight forms of lean waste comprise overproduction, waiting, transportation, overprocessing, unnecessary motion, defects, inventory, and underutilized human skills [12], [13], [14]. Their occurrence interrupts production flow, increases lead time and work-in-process, consumes additional resources, and limits the effective utilization of production capacity [15]. Lean practices therefore emphasize stabilizing work, improving process flow, preventing recurring problems, and reducing value-diminishing activities

[16], [17], [18]. The circular economy complements lean manufacturing by emphasizing the prevention of resource losses and the retention of products and materials at their highest feasible value [19], [20], [21]. Within manufacturing operations, circularity can be supported through efficient material utilization, defect prevention, reduction of overprocessing and rework, scrap segregation, recovery of suitable residual materials, and improved control over material flows [22], [23]. Circularity is therefore not limited to recycling after waste has been generated [24]. The integration of lean manufacturing and circular economy provides a complementary basis for investigating these issues [25], [26], [27]. Lean identifies process inefficiencies and non-value-adding activities, whereas circularity broadens the analysis toward material utilization, resource efficiency, scrap management, recovery, and value retention [28].

Rolling-stock manufacturing provides a relevant empirical setting for examining Lean-Circular factors because it commonly operates in a project-based or engineer-to-order environment [14]. This environment is characterized by relatively low production volumes, high product variety, complex process sequences, variable routing, and project-specific technical requirements. Changes in product specifications and production schedules may create fluctuations in work content, material requirements, workload, and coordination among production functions. Unlike repetitive manufacturing, where process abnormalities can be identified through stable cycle-time patterns, operational waste in rolling-stock production may vary between projects and product configurations. A process must therefore be examined according to its actual current-state conditions [14].

Within rolling-stock manufacturing, welding represents a particularly important and interdependent value stream [14]. The welding process does not consist solely of joining activities but includes material preparation, fit-up, positioning, welding, transportation between workstations, inspection, and corrective work [29], [30], [31]. Each stage depends on the availability of materials, welding equipment, fixtures, technical instructions, competent operators, and timely quality-control decisions [32]. A disruption at one stage may affect subsequent activities, leading to waiting, unnecessary movement, work-in-process accumulation, inspection delays, defects, reprocessing, and rework across the wider production flow [33]. Welding also directly affects material-value retention [31]. Over-welding consumes filler material, electricity, shielding gas, and equipment capacity beyond technical requirements [34]. Welding defects and corrective work require additional consumables, labor, inspection, grinding, cleaning, or reforming and may generate removed weld deposits and metal scrap [35]. Inappropriate welding sequences may contribute to distortion and repeated processing, while ineffective scrap segregation may limit the reuse or recovery of residual materials. Preventing these conditions is therefore relevant to both lean performance and circularity [25]. The welding value stream consequently provides an appropriate setting for examining how operational waste and material-value loss originate from common process conditions.

The case company operates in project-based rolling-stock manufacturing and was in the early stages of lean implementation. Lean practices had begun to be introduced in the bogie-frame production area because the materials and principal process requirements there were considered more stable than those in other project-based production areas. However, their application had not yet become fully established

or consistent. A systematic current-state diagnosis was therefore required before developing a future-state design or proposing more advanced improvement interventions. Value Stream Mapping (VSM) was selected as the first analytical tool because it represents the production process as an interconnected value stream rather than as a collection of isolated workstations [36], [37], [38]. A current-state VSM visualizes material and information flows, process sequence, cycle time, waiting time, work-in-process, transfers, inspection points, and corrective or rework loops [39], [40]. By comparing value-adding time with total production lead time, VSM shows where time and resources are consumed without directly transforming the product according to customer requirements [41]. It also identifies the points at which interruptions or accumulations affect the overall welding flow [42]. A reliable current-state VSM cannot be constructed solely from standard operating procedures or production documents [43], [44]. Direct observation and a gemba walk were therefore used to follow the physical flow of the product, verify the actual sequence of activities, record processing and waiting conditions, and clarify observed practices with personnel familiar with the production process [45]. These activities provided the empirical foundation for constructing the current-state map.

Although VSM provides an end-to-end representation of the value stream, it does not always describe individual activities in sufficient detail to distinguish how each activity contributes to customer value [46], [47], [48]. Process Activity Mapping (PAM) was therefore employed as the second analytical tool [49]. PAM decomposes the observed value stream into five activity categories: operation, transportation, inspection, storage, and delay [50]. Each activity is subsequently classified as value-adding (VA), necessary non-value-adding (NNVA), or non-value-adding (NVA) [51]. However, VSM, PAM, and waste classification primarily show what occurs and where. They do not independently explain why the identified conditions persist [52], [53]. Similarly, material losses may be influenced by over-welding, process variation, defect-prevention practices, and scrap-segregation procedures. Semi-structured cross-functional interviews were therefore incorporated into the analysis. Participants from production supervision, production management, and quality control provided complementary perspectives on production flow, welding requirements, material and equipment readiness, operator practices, inspection arrangements, corrective work, scrap handling, and coordination among organizational functions. The interview data were coded and analyzed thematically in NVivo. Thematic analysis served as the qualitative analytical method, while NVivo supported the organization, coding, comparison, and traceability of evidence across participants. The resulting themes were used to explain the technical, quality-related, human, organizational, and material-use factors associated with the waste identified through VSM and PAM. Previous studies have demonstrated the usefulness of VSM for identifying lead-time inefficiencies, waiting time, inventory, unnecessary transportation, and opportunities for improvement in manufacturing systems [54]. VSM has also been extended through system-dynamics simulation, digital technologies, and environmental or material-flow analysis [47]. Conventional VSM provides an aggregate representation of the value stream but may not classify individual activities sufficiently to distinguish VA, NNVA, and NVA work [55]. Consequently, limited evidence explains how system-level production flow, activity-level value classification, the eight forms of lean waste, and cross-functional qualitative explanations can be connected within a project-based rolling-stock welding value

stream. There is also limited understanding of how the operational waste identified at these analytical levels relates to material utilization, over-welding, defects, rework, scrap handling, residual material reuse, and production resource efficiency. This represents an important gap, particularly for manufacturing companies in the early stages of lean implementation that have not yet developed the quantitative data required for comprehensive circularity measurement.

To address this gap, the present study integrates direct observation, gemba walk, current-state VSM, PAM, systematic identification of the eight wastes, and NVivo-assisted thematic analysis. Current-state VSM establishes an end-to-end representation of the material and information flows. PAM decomposes the mapped flow into operation, transportation, inspection, storage, and delay activities and classifies them as VA, NNVA, or NVA. The eight-waste framework identifies how operational waste is manifested across the observed activities, while thematic analysis explains the factors associated with the identified waste and its implications for material-value retention. The novelty of this study does not lie in the individual use of VSM, PAM, waste identification, or NVivo, because each method is already established. Rather, the novelty lies in their structured integration into a sequential current-state diagnostic framework that connects four analytical levels: the overall production flow identified through VSM, the activity-level classification produced through PAM, the lean waste, and the underlying factors derived from NVivo-thematic analysis. This analytical sequence enables the study to explain what waste occurs, where it occurs, how it is manifested, and why it persists. It also extends conventional lean diagnosis by examining the qualitative Lean-Circular implications of the identified operational waste. Accordingly, this study addresses the following research questions: (1) What do the current-state VSM and PAM reveal about the VA, NNVA, and NVA activities within the observed welding value stream? (2) How are the eight forms of lean waste manifested across the activities and process stages identified through VSM and PAM? (3)What technical, quality-related, human, organizational, and material-use factors explain the identified waste and its Lean-Circular implications?

The study makes three principal contributions. First, it provides an empirical current-state diagnosis of a welding value stream in a project-based rolling-stock manufacturing environment at an early stage of lean implementation. Second, it integrates VSM, PAM, eight-waste identification, and thematic analysis to connect the forms and locations of operational waste with their underlying technical, quality-related, human, organizational, and material-use explanations. Third, it establishes a qualitative Lean-Circular baseline for material utilization, over-welding, defect prevention, rework, scrap handling, potential reuse of residual material, and production-resource efficiency. This baseline can support subsequent process improvement, future-state development, and more detailed quantitative circularity assessment without claiming that the present study measures circularity performance or evaluates an implemented improvement intervention.

2. Literature Review

2.1. Value stream mapping for operational waste identification

Value Stream Mapping (VSM) provides an end-to-end representation of the material and information flows required to deliver a product or service [56], [57]. Hines and Rich [58] introduced seven value-stream mapping tools and emphasized that different tools reveal different dimensions of waste. Subsequent studies have empirically applied VSM in manufacturing environments [59]. Seth et al. [60] combined direct observation, interviews, and VSM to investigate the processing side of the cottonseed oil supply chain. The study identified excessive cumulative inventory, unnecessary transportation, fragmented operations, and outdated processing technology. Its main strength lies in extending VSM beyond an individual production line to a broader supply-chain context. Nevertheless, the study focused primarily on productivity and capacity utilization, without explicitly examining how the identified waste affected material circularity. Rahani and Al-Ashraf [61] applied current-state and future-state VSM to an automotive component manufacturing process. Their study demonstrated that VSM could expose both visible and hidden waste, particularly waiting and other non-value-adding activities, and could support reductions in production lead time, work-in-process, and rejection rates. The study also revealed discrepancies between standardized procedures and actual shop-floor practices. However, its analysis was conducted in a relatively repetitive production environment and focused on operational improvements rather than on factors affecting the retention of material value. Similarly, Jasti and Sharma [62] used a case study approach to map material and information flows in an automotive components company. The current-state map was used to identify problems related to work-in-process, lead time, cycle time, line speed, and workforce requirements, followed by kaizen activities and the development of the future state. The results confirmed the effectiveness of VSM in improving process ratios and operational performance. However, the single-industry case limits generalization, and the study did not examine the human, quality-related, or organizational factors underlying the observed waste. These studies establish VSM as an effective diagnostic tool for locating waste, but they provide less detail on how individual activities contribute to value or loss [63]. Conventional VSM and PAM are nevertheless predominantly descriptive and static [64]. Stadnicka and Litwin [65] addressed the dynamic limitations of VSM through system dynamics modeling, but their approach requires structured quantitative data. For an initial industrial diagnosis, combining VSM and PAM with field-based waste identification offers a more feasible basis for examining the current state before simulation or future-state design.

2.2. Extending VSM toward resource efficiency and circularity

The environmental limitations of conventional VSM have encouraged researchers to incorporate resource consumption and environmental waste into value-stream analysis [66], [67]. Choudhary et al. [68] developed Green Integrated Value Stream Mapping (GIVSM) and applied it to a packaging manufacturing small-and medium-sized enterprise in the United Kingdom. The study showed that lean

and green practices could generate synergistic improvements in operational and environmental performance. Valamede and Akkari [69] extended VSM in a different direction by examining its integration with Industry 4.0 technologies. Their conceptual study identified synergies between lean tools and technologies such as big-data analytics, cloud systems, virtual simulation, and augmented reality. Digital VSM was positioned as a mechanism for improving process visibility, information availability, and waste detection. Although this approach enhances the timeliness and accuracy of process information, it concentrates on digital integration and automation. It does not directly explain how technical, human, organizational, and material-use conditions influence operational waste or circular practices. Akter et al. [70] examined material waste management from a circular-economy perspective in the textile and apparel industry. Using an exploratory multiple-case design, the study collected data from 17 factories through semi-structured questionnaires, observations, and material-stream mapping. It identified and categorized waste across different production stages, estimated the associated economic losses, and traced informal flows of residual materials. The study is particularly relevant because it connects material-flow visualization with opportunities for reuse, recycling, and value recovery. However, it focuses primarily on material-waste streams and post-production recovery within the textile supply chain. The locations of conventional lean waste, such as waiting, unnecessary motion, work-in-process, and repeated processing, were not systematically linked to the technical and organizational factors that generated material losses. The distinction between lean-green and Lean-Circular analysis is important. Lean-green studies generally emphasize reducing environmental burdens, such as energy consumption, emissions, and waste generation [71]. Therefore, reducing waste does not automatically demonstrate circularity [72]. Lean and circular perspectives must consequently be connected at both the production flow level and the factors influencing material use [23].

2.3. Human and organizational factors in lean implementation

Lean implementation requires more than the technical application of waste-identification and process-improvement tools [73]. Its effectiveness is also influenced by the organizational conditions that determine how consistently lean practices are understood, communicated, and maintained [74]. Technical improvements may not be sustained when employees receive insufficient training, operational information is fragmented, coordination is ineffective, or management support is inconsistent [75]. Nurmalasari et al.[76] examined the causal relationships among factors influencing the implementation of Safety, Quality, Cost, Delivery, and People (SQCDP) as a lean management tool at an Indonesian aerospace manufacturer. Using purposive expert sampling and the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, the study evaluated nine factors: integrated information systems, training, top-management support, work discipline, organizational communication, work culture, employee engagement, work motivation, and multifunctional teams. The results identified work culture as the most important factor, followed by work discipline, while top-management support, training, motivation, and employee engagement contributed to the causal structure of lean implementation. The study provides evidence that lean performance is shaped by interdependent human and organizational conditions rather than by the isolated use of lean tools [76]. Its aerospace context is relevant to rolling-

stock manufacturing because both industries involve complex products, stringent quality requirements, specialized production activities, and extensive coordination among engineering, production, and quality functions. Nevertheless, the study focused on the organizational implementation of SQCDP and used expert-based causal modeling. It did not map operational waste, examine a physical production flow, or address circularity-related material practices. The present study extends this perspective by investigating how human and organizational factors identified from cross-functional interviews relate to waste observed directly within a welding value stream.

2.4. Thematic Analysis

Thematic coding enables these perspectives to be compared and organized into technical, quality-related, human, organizational, and material-use themes [77]. NVivo supports this analysis by maintaining links between codes, themes, participants, and the underlying interview evidence [78]. Few studies explicitly connect system-level VSM evidence [64], activity-level PAM classifications [30], the eight waste categories [2], [79], [80], and factors derived from cross-functional thematic analysis [81]. Consequently, limited evidence exists on how observable activities and waste locations can be systematically linked to technical, quality-related, human, organizational, and material-use conditions. Table 1 compares the reviewed studies by industrial context, method, contribution, and limitations. The comparison positions the present study as an integration of current-state VSM, PAM, eight-waste identification, and cross-functional thematic analysis in a project-based rolling-stock welding process.

Table 1
Comparison of previous study

No.	Study	Context and Method	Main Findings and Strengths	Limitations relative to the present study
1	Hines and Rich [58]	Conceptual development of seven value stream mapping	Established a structured foundation for identifying different categories of waste across value streams	Conceptual rather than empirical; does not address circularity or cross-functional causal factors
2	Seth et al. [60]	Cottonseed-oil supply chain; observation, interviews, and VSM	Identified excessive inventory, transportation, fragmentation, and technological inefficiency across a supply chain	Focuses on productivity and capacity utilization; does not examine material-value retention
3	Rahani and Al-Ashraf [61]	Automotive-component production; gemba, current-state VSM, future-state VSM, and lean improvement	Revealed hidden waste, waiting, differences between standardized and actual work, and opportunities to reduce lead time and rejection	Repetitive manufacturing context; limited analysis of circularity-related and organizational factors
4	Jasti and Sharma [62]	Automotive-component manufacturing; case study, VSM, kaizen, and future-state mapping	Improved process ratio, lead time, cycle time, inventory, line speed, and workforce utilization	Single-industry case; focused on operational performance and proposed improvements
5	Stadnicka and Litwin [65]	Automotive production; extended VSM and system-dynamics simulation	Explained the effects of disturbances and inventory policies on production volume and work-in-process	Requires quantitative modelling; does not incorporate cross-functional qualitative explanations or circularity
6	Choudhary et al. [68]	UK packaging SME; Green Integrated VSM	Integrated operational indicators with carbon, material, energy, transportation, and waste measures	Lean–green rather than explicitly Lean-Circular; depends on quantitative environmental data
7	Valamede and Akkari [82]	Conceptual Lean 4.0 framework	Identified synergies between VSM, digital technologies, information visibility, and waste reduction	Conceptual and technology-oriented; does not empirically examine welding or material-value retention

No.	Study	Context and Method	Main Findings and Strengths	Limitations relative to the present study
8	Akter et al. [70]	Textile and apparel sector; 17-company multiple case, questionnaires, observations, and material-stream mapping	Categorized material waste, estimated economic loss, and identified reuse and recovery opportunities	Emphasizes material streams and post-production recovery; limited connection with operational lean waste
9	Larsson et al. [83]	ETO electrical engineering; action research, digital VSM, case study, and ten employee interviews	Identified waiting, documentation inefficiency, and non-value-adding engineering work in a project-based environment	Examines knowledge work rather than physical production; does not analyze welding, rework, or scrap
10	Nurmalasari et al. [76]	Indonesian aerospace manufacturing; purposive expert sampling and DEMATEL analysis of Lean manufacturing implementation factors	Identified causal relationships among nine lean-implementation factors; work culture and work discipline emerged as the most important factors	Focuses on organizational implementation of SQCDP; does not map production waste or examine material-value retention and circularity

2.5. Research Position and Novelty

The literature indicates four related gaps. First, most empirical VSM studies focus on repetitive manufacturing, whereas physical production in project-based rolling-stock environments remains underexamined. Second, activity-level PAM is not consistently integrated with end-to-end VSM in studies of complex welding flows. Third, environmental and circular extensions often rely on quantitative data on carbon, energy, or material flows that may be unavailable during an initial diagnosis. Fourth, limited research systematically links the locations and activity classifications of observable waste with technical, quality-related, human, organizational, and material-use factors derived from cross-functional thematic analysis. The present study addresses these gaps through a sequential analytical chain. Current-state VSM identifies the structure, timing, work-in-process, transfers, and corrective loops of the welding value stream. PAM decomposes the flow into operation, transportation, inspection, storage, and delay and evaluates each activity as VA, NNVA, or NVA. The eight-waste framework then interprets the operational manifestations of loss, while NVivo-assisted thematic analysis explains the associated cross-functional factors. The novelty lies not in proposing a quantitative circularity indicator or future-state model, but in integrating these four analytical layers to establish an empirically grounded qualitative Lean-Circular baseline for project-based welding production.

3. Methods

3.1. Research Design

This study employed an exploratory single-case design to diagnose operational waste and identify Lean-Circular factors [84] in a project-based rolling-stock welding process. The case-study design enabled the production flow to be examined in its actual operational and organizational context. The analytical scope was limited to the current state; the study neither evaluated an implemented intervention nor developed a future-state map. The unit of analysis was the welding value stream, covering material and station readiness, component fabrication and fit-up, welding, interstation transfer, temporary work-in-process, quality inspection, bogie-frame assembly, and corrective work. The company, product, and commercially sensitive information were anonymized. The research followed six stages: (1) direct observation and gemba walk; (2) current-state VSM development; (3) PAM classification; (4) eight-waste identification; (5) semi-structured interviews and NVivo-assisted thematic analysis; and (6) integration and triangulation of the process and qualitative findings. Figure 1 illustrates the framework used to connect process evidence with its Lean-Circular interpretations.

3.2. Data Collection

Data were collected through direct observation, gemba walk, and semi-structured interviews. The fieldwork was conducted from April to August 2026 in the selected welding production area. These methods were used because formal procedures and production records may not fully capture interruptions, informal coordination, searching, repeated movement, waiting, and corrective activities occurring during actual production. Direct observation was conducted by following the production sequence across the selected welding value stream. The observed data included the sequence of activities, processing time, waiting time, movement of materials and components, work-in-process, inspection points, process interruptions, defects, and rework loops [80], [85], [86], [87]. Field notes were used to record the observed activities and the contextual conditions accompanying them. A gemba walk was conducted along the actual path followed by materials and components [88]. It enabled the researchers to verify the sequence of physical processes, identify discrepancies between prescribed and performed work, and clarify shop-floor conditions with personnel familiar with the process. The observations and gemba walk focused on identifying the forms of lean waste and their locations, rather than measuring individual operator performance. Interview participants represented production and quality-control functions and were selected purposively because they possessed direct knowledge[89] of the welding value stream. They included production supervisors, production managers, and quality-control personnel involved in production planning, operational supervision, welding execution, inspection, or corrective decisions. The sampling objective was cross-functional relevance and information richness rather than statistical representation. The participant-selection criteria were: (1) direct involvement in or responsibility for the selected welding process; (2) sufficient knowledge of its production and quality-control activities; and (3) experience in explaining operational problems, material utilization, defects, rework, inspection, or interdepartmental coordination. The inclusion of participants from different functions was intended to capture complementary perspectives rather than relying on a single organizational viewpoint. Interviews were conducted face-to-face using a semi-structured guide covering production flow, material and equipment readiness, welding requirements, inspection, defects and rework, waste-reduction practices, scrap handling, resource use, and interdepartmental coordination.

The interviews were transcribed and prepared for analysis in NVivo. Identifying information concerning the company and participants was removed from the analytical dataset.

3.3. Current-State Value Stream Mapping

The current-state VSM was constructed from observations and gemba-walk evidence and represented the actual material and information flows [90]across the selected welding process. For each process stage, the researchers documented the activity sequence, processing time, interprocess waiting, work-in-process, transfers, inspection points, information exchange, and corrective loops. Total processing time, waiting time, and production lead time were aggregated from the observed timeline. Because component stations operated in parallel and converged during bogie-frame assembly, recorded WIP waiting was interpreted as product-flow delay rather than complete workshop inactivity.

3.4. Process activity mapping and waste identification

Process Activity Mapping (PAM) translated the current-state VSM into five activity types: operation (O), transportation (T), inspection (I), storage (S), and delay (D) [91], [92]. Each observed activity was then classified as value-adding (VA), necessary non-value-adding (NNVA), or non-value-adding (NVA) [51]. After PAM classification, the observed evidence was interpreted using eight waste categories: Overproduction, Waiting, Transportation, Overprocessing, Motion, Defect, Inventory, and Underutilized Skill [93]. Waste was reported only when supported by observation, VSM/PAM evidence, or interview confirmation.

3.5. NVivo-assisted thematic analysis

The interview data were analyzed using thematic analysis, with NVivo employed to support data organization, coding, comparison, and evidence traceability [94]. As shown in Fig. 1, thematic analysis was selected because the factors associated with operational waste and material-value retention involved technical practices, quality requirements, human behavior, and organizational arrangements that could not be adequately represented by the current-state VSM alone. The analysis followed six stages: familiarization with transcripts and field notes; initial coding; grouping related codes into candidate themes; reviewing themes against coded extracts and the complete dataset; defining and naming themes; and interpreting the themes [95], [96] in relation to VSM locations, PAM classifications, and the eight identified wastes. A hybrid deductive–inductive coding strategy was used. The deductive component was informed by lean waste categories, circularity-related material practices, and established lean implementation factors, including training, management support, work discipline, organizational communication, work culture, employee engagement, work motivation, and cross-functional collaboration [81]. The inductive component allowed additional factors specific to the welding process to emerge from the participants' accounts. Consequently, the previous framework served as a sensitizing structure rather than a fixed coding scheme. Codes with similar meanings were subsequently consolidated to reduce overlap and maintain conceptual clarity. Coding-reference counts and percentage coverage generated by NVivo were used descriptively to indicate the relative prominence of themes within the interview dataset [78]. These values were not interpreted as statistical weights, causal effects,

or measurements of Lean-Circular performance. Coding was conducted by the lead researcher using a coding framework developed from the study's deductive categories and inductively emerging codes. To maintain analytical consistency, code definitions, inclusion and exclusion criteria, and representative extracts were documented in a working codebook. The coding structure was reviewed iteratively by comparing coded extracts across participants and examining their consistency with the complete transcripts, field notes, and observed process conditions. Codes with overlapping meanings were discussed within the research team and either clarified, merged, or retained as separate categories according to their conceptual distinctions. Theme interpretations were subsequently cross-checked against the current-state VSM, PAM classifications, and evidence of eight wastes. This triangulation was used to ensure that the reported themes were grounded in both participants' accounts and observable production conditions rather than in coding-reference frequencies alone. Participants were informed of the research purpose, and identifying information relating to the company and individual participants was removed from the analytical dataset. Data collection and reporting were also conducted in accordance with the confidentiality provisions agreed upon with the case company.

3.6. Trustworthiness and analytical rigor

Credibility was supported through methodological and source triangulation [97]. Methodological triangulation compared direct observation, gemba walk, VSM, PAM, eight-waste identification, and interview evidence. Source triangulation compared perspectives from production supervision, management, and quality control. Interpretations were retained when they were consistent with the observed process conditions and supported by relevant cross-functional evidence. Dependability was maintained through documentation of field observations, VSM data, interview transcripts, coding decisions, and theme development. NVivo provided an auditable connection between the reported themes and their supporting interview extracts [98]. Confirmability was strengthened by distinguishing direct field evidence from the researchers' interpretation. Transferability was supported by clearly defining the industrial context, process scope, participant roles, and analytical boundaries. Nevertheless, because this study examined a single welding value stream within a single rolling-stock manufacturing company, the findings are analytically transferable to comparable project-based environments rather than statistically generalizable across all manufacturing organizations.

4. Results and Discussion

4.1. Current-state value stream mapping

The current-state Value Stream Mapping (VSM) was constructed from direct observation and gemba walks across the side-beam, transom, end-beam, and bogie-frame assembly areas. The process boundary begins with the release and preparation of component materials and continues through component fabrication, fit-up, welding, interstation transfer, bogie-frame assembly, and quality verification. Figure 2 consolidates the observed material and information flows, process cycle times, interprocess waiting, WIP locations, inspection-related decisions, and corrective loops into a single end-

to-end representation. As illustrated in Fig. 2, the value stream is convergent rather than purely linear. Side beams, transom components, end beams, and other subassemblies are processed at different stations before being brought together during bogie-frame assembly. Work is therefore performed in parallel. When a station completes a component or subassembly, its operators continue processing the next available WIP rather than waiting for the same unit to complete the entire value stream. The WIP symbols consequently represent components or subassemblies awaiting downstream capacity, inspection, material readiness, transfer, or assembly, even though upstream operators may remain occupied with subsequent units.

This operating pattern has two important analytical implications. First, the sum of the cycle and waiting times represents the time the mapped product flow experiences; it does not imply that the entire workshop remains inactive during every waiting interval. Second, high local activity can coexist with poor end-to-end flow. When upstream stations release work faster than downstream stations can receive, inspect, or assemble it, local productivity is converted into interprocess inventory. Continuous operator activity must therefore be distinguished from continuous product flow. The timeline in Fig. 2 was aggregated to compare processing and waiting. As summarized in Table 2, total processing time was 324,867 seconds (90.24 hours), while interprocess waiting reached 284,491 seconds (79.03 hours). The combined production lead time was therefore 609,358 seconds, equivalent to 169.27 hours or 10.58 working days under two eight-hour shifts per day. Thus, nearly half of the measured lead time was consumed while the product was not being transformed.

Table 2
Distribution of VA, NNVA, and NVA time

Category	Details	Seconds	Hours	Percentage	Days (16 h (2shift)/day)
VA	Direct processing, assembly, and welding	324,267	90.07	53.21%	5.63
NNVA	Explicitly timed necessary transportation	600	0.17	0.10%	0.01
NVA	Measured interprocess waiting	284,491	79.03	46.69%	4.94
Total	**Measured production lead time**	**609,358**	**169.27**	**100%**	**10.58**

Table 2 separates the processing total into 324,267 seconds of direct value-adding work and 600 seconds of explicitly recorded necessary transportation. The resulting VA ratio was 53.21%, NNVA was 0.10%, and measured NVA waiting was 46.69%. Waiting was consequently the largest directly quantified form of waste. This proportion is conservative because setup, inspection, cleaning, tool preparation, and similar supporting activities were not timed separately in every process box. A more detailed elemental time study could therefore reclassify part of the current processing total from VA to NNVA or NVA. The time structure indicates that the principal performance issue is not simply the duration of welding

operations. The larger concern is the synchronization of component readiness, downstream capacity, inspection, information, and material movement across parallel stations. Reducing the cycle time of one station without controlling WIP release may merely move the queue to another point. The current-state diagnosis therefore directs attention toward flow control, readiness, quality release, and interstation coordination.

4.2. Process Activity Mapping

Process Activity Mapping (PAM) was used to translate the current-state VSM into five activity types: operation (O), transportation (T), inspection (I), storage (S), and delay (D). Each activity was then classified as VA, NVA, or NNVA. These PAM codes describe the type and value contribution of an activity; they are distinct from the eight lean-waste categories used in this study. Table 3 defines the PAM abbreviations applied in the activity mapping.

Table 3
Glossary of PAM activity and value classification**s**

Code	Term	Operational definition
O	Operation	An activity that changes the form, characteristics, or assembly status of the product.
T	Transportation	Movement of material, components, or products between locations without changing their physical characteristics.
I	Inspection	Verification of dimensions, weld quality, specifications, or product conformity.
S	Storage	Material or product is intentionally stored and its release or movement is administratively controlled.
D	Delay	Material or product stops temporarily while waiting for capacity, material, equipment, information, inspection, or a decision.
VA	Value-added	An activity that directly transforms the product according to customer or technical requirements and is performed correctly the first time.
NVA	Non-value-added	An activity that consumes time or resources without adding value and should be reduced or eliminated.
NNVA	Necessary non-value-added	An activity that does not directly transform the product but is currently required for technical, quality, safety, regulatory, or operational reasons.
WIP	Work-in-process	Material, components, or subassemblies that have entered production but have not become finished products.

Table 4
Process Activity Mapping of the observed welding value stream

Process area	Observed activity	O	T	I	S	D	VA/NVA/NNVA
Material and station readiness	Checking availability of materials, welding equipment, tools, fixtures, and technical documents	O					NNVA
Side-beam production	Fit-up, positioning, assembly, and welding of side-beam components	O					VA
Side-beam transfer	Movement to transit/WIP area before the subsequent process		T				NNVA
Transom production	Fit-up, assembly, and welding of transom components	O					VA
Transom transfer	Movement to the next assembly or transit area		T				NNVA
End-beam production	Fit-up, assembly, and welding of end-beam components	O					VA
End-beam transfer	Movement to the bogie-frame assembly area		T				NNVA
Bogie-frame assembly	Positioning and assembly of side beams, transom, end beams, and brackets	O					VA
Welding	Welding of the assembled bogie-frame structure	O					VA
Quality control	Dimensional and weld-quality verification			I			NNVA
Temporary WIP	Components/subassemblies held in transit or interprocess buffers				S		NVA
Interprocess waiting	Waiting for downstream capacity, inspection, information, material, fixture, or equipment					D	NVA
Corrective processing	Reforming, repair welding, repeated grinding/cleaning, or removal of excess weld deposit	O					NVA

The classification logic in Table 3 was applied to each observed activity. Operations that physically changed, joined, or assembled the product were classified as VA when performed correctly for the first time. Transportation, inspection, and readiness activities were classified as NNVA when they were presently required to sustain technical, quality, or operational control. Waiting, avoidable WIP accumulation, repeated processing, and corrective work were classified as NVA. Table 4 presents the resulting activity-level mapping. As shown in Table 4, the main fabrication, fit-up, assembly, and welding steps were operations, whereas component transfers, quality verification, temporary WIP, and

interprocess waiting represented supporting or non-value-adding activities. Corrective processing was also coded as an operation because it physically altered the product, but it was classified as NVA because it restored conformity rather than creating customer-required value. This distinction is important: the PAM activity type describes what happens, whereas the VA–NVA–NNVA classification assesses whether that activity adds value. However, accumulation becomes NVA when it results from imbalanced capacity, delayed inspection, incomplete material or fixture readiness, unclear priorities, or uncontrolled upstream release. In the observed system, parallel working allowed operators to remain active, but the product continued to accumulate waiting time. The PAM therefore confirms the VSM finding that station utilization and product-flow efficiency are not equivalent.

4.3. Waste identified in the welding process

The activity classifications in Table 4 were subsequently interpreted using the eight waste categories specified in the research proposal: overproduction, waiting, transportation, overprocessing, motion, defect, inventory, and underutilized skill. Table 5 summarizes how each waste appeared in the current state and clarifies its operational and material-value implications. Table 5 shows that waiting was the dominant quantified waste, but the eight wastes were mutually reinforcing. Continued production at an upstream station before downstream readiness created overproduction at the process level and increased inventory in the form of WIP. The additional WIP then required storage space, status checking, prioritization, and further handling. Transportation and motion arose when materials, tools, fixtures, or information were not positioned at the point of use. These conditions extended lead time even when the actual welding cycle remained unchanged.

Table 5
Waste and Lean-Circular implications

Waste	Evidence in the current state	Operational effect	Circular implication
Overproduction	Upstream stations continue producing or releasing subsequent WIP before downstream stations are ready	Excess WIP and imbalance between stations	More material remains tied up in unfinished products
Waiting	284,491 seconds of measured interprocess waiting; repeated WIP and transit points	Longer throughput time and delayed completion	Energy, facilities, and production resources remain committed without transformation
Transportation	Repeated transfers between component and assembly areas; at least 600 seconds explicitly timed	Handling effort, congestion, and damage risk	Additional equipment and energy use
Overprocessing	Over-welding, excess-deposit removal, repeated cleaning/grinding, and reforming	Longer cycle time and unnecessary equipment use	Excess filler, electricity, gas, consumables, and metal removal
Motion	Searching or walking for tools, fixtures, materials, information, and quality confirmation	Lower operator productivity and inconsistent work	Additional use of time and supporting resources
Defect	Corrective welding, reforming, repeated inspection, and other rework	Repeated processing and schedule disruption	Additional material and energy consumption; increased scrap
Inventory	Buffers and WIP containing successive components between stations	Problems are concealed and floor space is occupied	Material value remains locked in unfinished units
Underutilized Skill	Operator knowledge, competence, experience, and improvement capability are not used optimally	Recurring abnormalities and slower problem resolution	Lost opportunities to prevent operational and resource waste

Overprocessing and defects were the most direct bridge between lean waste and circularity [99]. Over-welding used filler material, electricity, shielding gas, worker, and equipment capacity beyond the technical requirement. Defects, distortion, and nonconformity generated repair welding, reforming, repeated grinding or cleaning, and additional inspection. Although these actions were necessary to restore product conformity, they did not create new customer value and could also generate removed weld deposits or other scrap. Underutilized skill further contributed when operator experience and shop-floor knowledge were not fully used to prevent recurrence or improve standard work. The waste analysis therefore indicates two connected improvement directions. Flow-related improvement concerns WIP release, synchronization, readiness, layout, and inspection response. Process- and material-related

improvement concerns welding-sequence compliance, weld-size control, first-time quality, rework prevention, scrap segregation, and the possible reuse of suitable residual material. These directions were explored further through the interview analysis

4.4. NVivo-assisted thematic analysis

A total of four participants were interviewed: two production supervisors, one production manager, and one quality-control supervisor. Participants had 7–10 years of relevant experience. Interviews lasted approximately 1 hour 30 minutes to 1 hour 45 minutes, were conducted in Indonesian, and were audio-recorded with consent. Data collection continued until information sufficiency was reached. Table 6 summarizes the profile of the anonymous participant.

Table 6
Anonymous profile of interview participants.

Participant code	Function	Position	Relevant experience	Interview duration
P1	Production	Supervisor	7 years	1 hour 40 minutes
P2	Production	Supervisor	10 years	1 hour 40 minutes
Q1	Quality control	Supervisor	9 years	1 hour 30 minutes
P3	Production	Manager	10 years	1 hour 45 minutes

The interview evidence was analyzed thematically with NVivo to explain the technical and organizational conditions underlying the waste located through VSM and classified through PAM. The coding process generated 138 references across 10 subthemes, grouped into 5 principal themes: technical and process, quality, human and organizational, lean manufacturing, and circularity. Figure 3 presents the relative composition of these themes, while Fig. 4 shows the distribution of coding references across categories. Table 7 confirms that compliance with welding standards and sequences was the most frequently coded factor, with 34 references, accounting for 24.64% of the total coding. Inspection and quality control accounted for 27 references (19.57%), while the readiness of materials, tools, and welding facilities accounted for 19 references (13.77%). Coordination and interdepartmental information exchange contributed 15 references (10.87%), and operator competence and discipline contributed 11 references (7.97%). Together, these five subthemes represented 76.82% of all coding references, indicating that the dominant explanations concerned process conformance, quality release, resource readiness, coordination, and human execution. The technical-and-process theme linked waste to compliance with welding sequences and the readiness of materials, tools, fixtures, and facilities. Deviation from prescribed sequences could increase distortion, corrective work, and repeated processing, while incomplete readiness could interrupt otherwise available workers and capacity. The quality theme explained that inspection is necessary for product conformity but may become a flow constraint when inspection requests, documentation, inspector availability, or quality decisions are not synchronized with production.

Cross-functional interview evidence further clarified the relationship between process readiness and quality-control activities. Participants consistently indicated that production continuity depended not only on operator and workstation availability but also on the timely availability of materials, tools, fixtures, welding equipment, technical documents, and supporting facilities. When one of these resources was unavailable or already in use at another station, the affected work could not proceed as scheduled, even when operators and work in process were present. Such conditions contributed to searching, temporary stoppages, repeated material handling, work-in-process accumulation, and the rescheduling of production priorities. The interview evidence also showed that quality control performed a dual role within the value stream. Inspection was essential for ensuring dimensional accuracy and weld conformity; however, the process could become a flow constraint when inspection requests, documentation, inspector availability, and quality-release decisions were not synchronized with production completion. Components awaiting inspection or corrective decisions consequently remained in interprocess buffers, increasing waiting time and delaying their release to subsequent assembly stages. These accounts support the VSM and PAM findings by demonstrating that the observed waiting was driven by interdependent conditions of resource readiness and quality release rather than by workstation inactivity alone. As one production participant explained, "*Production could not continue when the required materials, tools, or fixtures were not available at the workstation, even though the operators were ready to work*" (P1). A quality-control participant similarly stated that "*completed components sometimes had to wait for inspection and quality release before they could move to the next process*" (Q1).

The human-and-organizational theme showed that operational waste was influenced not only by equipment limitations but also by coordination and operator practices. Delays in communicating material status, production priorities, inspection requests, or corrective decisions could lead to delays, unnecessary movement, and work-in-process accumulation. Operator competence and discipline also affected welding stability. Operators needed to understand technical requirements, maintain welding parameters, follow the correct sequence, and comply with standard procedures. When operator knowledge was not incorporated into problem-solving, recurring abnormalities and waste could remain unresolved. Overall, improving the welding value stream requires better cross-functional communication, clear responsibilities, consistent standard work, and operator involvement in identifying and resolving process problems. As one production supervisor explained, "*Operator competence and discipline are essential because welding must follow the specified parameters, sequence, and standard procedures. When these requirements are not followed consistently, defects and rework may occur*" (P1).

Table 6
Distribution of NVivo coding references

Theme	Subtheme	Ref	Percentage
Technical and process	Compliance with welding standards and sequences	34	24.64%
Technical and process	Readiness of materials, tools, and welding facilities	19	13.77%
Quality	Inspection and quality control	27	19.57%
Quality	Prevention of defects, over-welding, and rework	7	5.07%
Human and organizational	Coordination and interdepartmental information exchange	15	10.87%
Human and organizational	Operator competence and discipline	11	7.97%
Lean manufacturing	Reduction of waste in welding	7	5.07%
Lean manufacturing	Stability of lean implementation	7	5.07%
Circularity	Scrap segregation and potential reuse	7	5.07%
Circularity	Efficient use of production resources	4	2.90%
Total		**138**	**100%**

The lean-manufacturing subthemes of waste reduction in welding and the stability of lean implementation each accounted for 7 references. Their relatively modest coverage is consistent with an organization in the early stages of lean implementation: waste-reduction practices had begun to emerge, but they were not yet consistently embedded across stations and shifts. This condition helps explain the coexistence of local improvement efforts with persistent waiting, WIP, transportation, and rework. Circularity-related themes accounted for 11 of the 138 coding references, comprising scrap segregation and potential reuse (seven references) and the efficient use of production resources (four references). Although these themes were less frequently coded than operational and quality-related concerns, their lower frequency should not be interpreted as indicating lower practical importance or weaker causal influence. Coding-reference frequencies represent the prominence of issues within the qualitative dataset rather than statistical weights or measures of impact. The findings indicate that circularity was not yet managed as a distinct operational objective but emerged through practices associated with material loss prevention, resource efficiency, and residual-material value retention. In particular, inadequate scrap segregation and traceability may limit opportunities for reuse or recovery, while excessive material consumption, over-welding, defects, and rework can reduce material value and increase resource requirements. Thus, the circularity evidence in this study provides a qualitative process-level diagnosis of barriers to material-value retention rather than a quantitative assessment of circularity performance. As one production participant explained, "*Residual welding materials and metal*

scrap need to be separated and identified properly because mixed or untraceable scrap is more difficult to reuse or recover" (P3).

4.5. Integrated VSM-PAM-NVivo interpretation

The findings were integrated by linking the observable conditions in the VSM, their activity and value classifications in PAM, and their underlying explanations in the NVivo themes. VSM identified where processing, waiting, transfer, WIP, inspection, and corrective loops occurred. PAM clarified whether the associated activities transformed the product, supported the process without directly adding value, or represented avoidable loss. NVivo then explained why these conditions persisted.

Table 7
Triangulation of VSM, PAM, waste, and NVivo findings

Observed condition	VSM/PAM evidence	Related waste	NVivo explanation	Lean-Circular significance
Interprocess waiting and WIP accumulation	284,491 seconds of waiting; delay and storage between parallel stations	Waiting, overproduction, inventory	Material/tool readiness; coordination and information exchange; inspection timing	Long lead time and material value locked in unfinished products
Repeated component movement and searching	Transportation between component, transit, and assembly areas; supporting motion	Transportation, motion	Readiness of materials, tools, fixtures, and facilities; coordination	Additional handling, labour, equipment use, and damage risk
Over-welding and repeated processing	Corrective operation classified as NVA	Overprocessing	Welding-standard and sequence compliance; competence and discipline	Excess filler, energy, gas, consumables, and equipment capacity
Defects, distortion, and rework	Corrective loops, repeated processing, and additional inspection	Defect	Inspection and quality control; sequence compliance; operator competence	Additional resource consumption, scrap generation, and reduced first-time quality
Inconsistent lean and material-retention practices	Waste remains across stations; limited explicit circular controls	Underutilized skill and related recurring waste	Lean-implementation stability; waste reduction; scrap segregation and reuse	Lost improvement knowledge and limited retention of residual-material value

Table 7 summarizes this triangulation. As shown in Table 7, the dominant quantified problem of waiting was not an isolated delay. It was connected to readiness, inspection, coordination, and the release of

WIP across parallel stations. Similarly, over-welding and rework were not merely quality problems; they were also sources of overprocessing, additional material and energy consumption, and potential scrap. The combined evidence therefore shows that operational waste and material-value loss frequently arose from the same technical and organizational conditions. The resulting diagnosis establishes a qualitative Lean-Circular baseline. Operational improvement should focus on end-to-end flow rather than simply keeping each station continuously occupied. Relevant directions include clearer WIP limits and priorities, readiness control before release, coordinated inspection, improved point-of-use availability, compliance with welding standards and sequences, prevention of over-welding and rework, use of operator knowledge in structured problem solving, and segregation and traceability of residual material. These directions are derived from the current-state evidence and should be validated and developed into specific interventions in subsequent improvement work. The analysis does not constitute a future-state design or a quantitative circularity assessment. It does, however, identify the process locations, activity types, waste manifestations, and cross-functional factors that require attention before such assessments are undertaken. In this way, the integration of VSM, PAM, and NVivo provides a coherent explanation of what waste occurs, where it occurs, and why it persists in the observed welding value stream.

5. Conclusion

This study used direct observation, gemba walks, Value Stream Mapping (VSM), Process Activity Mapping (PAM), eight-waste identification, and NVivo-assisted thematic analysis to diagnose a project-based rolling-stock welding value stream. Of the total 609,358 seconds (169.27 hours) of lead time, 46.69% was non-value-adding waiting. The comprehensive evidence indicated that all eight lean wastes were linked to technical, quality, resource-readiness, human, and organizational factors, rather than isolated workstation issues. Theoretically, the study extends traditional value-stream diagnosis by integrating four levels: end-to-end flow via VSM, activity-level value classification through PAM, manifestation of the eight lean wastes, and cross-functional insights from thematic analysis. This approach shows that operational waste and material-value loss originate from shared socio-technical conditions, offering a qualitative Lean-Circular baseline for cleaner-production research in project-based manufacturing.

In practice, for the case company, improvements should focus on the end-to-end flow rather than optimizing individual workstations. Key actions include controlling WIP release, verifying material, tool, and fixture readiness before production, coordinating inspection and quality release, enhancing point-of-use availability, and involving operators in structured problem-solving. Ensuring compliance with welding standards, preventing over-welding and rework, and managing residual materials through segregation and traceability are essential, as they influence lead time, resource use, scrap, and material value. The findings, based on a single welding value stream in one rolling-stock manufacturer, reflect a current-state diagnosis; they are transferable analytically but not statistically generalizable. The study did not evaluate an intervention, develop a future-state map, or quantify circularity through material-flow analysis, lifecycle assessment, energy metering, or material circularity indicators. Thematic prominence indicated

by coding-reference frequencies should not be interpreted as causal or statistical weights. Future research should validate these priorities with a broader group of experts and operators, develop and test a future-state VSM, and evaluate interventions over time. Multi-case studies could assess whether this framework applies to other project-based welding and engineer-to-order environments. Quantitative measures should track changes in lead time, WIP, first-pass quality, defects, resource and energy use, scrap, reuse, and residual-material recovery.

Declarations

Conflicts of Interest

The authors declare that they have no known financial or non-financial competing interests that could have influenced the work reported in this manuscript.

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Author Contributions

Niza Nurmalasari contributed to the conceptualization and design of the study, development of the methodology, project administration, fieldwork coordination, data analysis, interpretation of the findings, visualization, and preparation of the original manuscript. Alfi Tranggono Agus Salim contributed to the welding process analysis, validation of manufacturing data, and technical interpretation of the findings. Galuh Kusuma Wardani contributed to the qualitative methodology, thematic analysis, interpretation of the findings, and review and editing of the manuscript. Netty Lisdiantini contributed to the research design, organizational interpretation, data validation, and critical revision of the manuscript. Sukoroto contributed to the technical validation of the welding process data, the interpretation of the Value Stream Mapping and Process Activity Mapping results, and the review and editing of the manuscript. Rohit Efendi Saputra, Florentina Carlo Awandya, Karima Nazhirohtul Sabrina, Aditya Febrianto, Arina Mahiroh, and Rizka Shofia Ahyaningrum contributed to the field investigation, direct observation, gemba walks, process-time data collection, documentation of the welding value stream, and preparation of the research data. All authors reviewed and commented on previous versions of the manuscript, read and approved the final manuscript, and agreed to be accountable for the content of the work.

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Figures

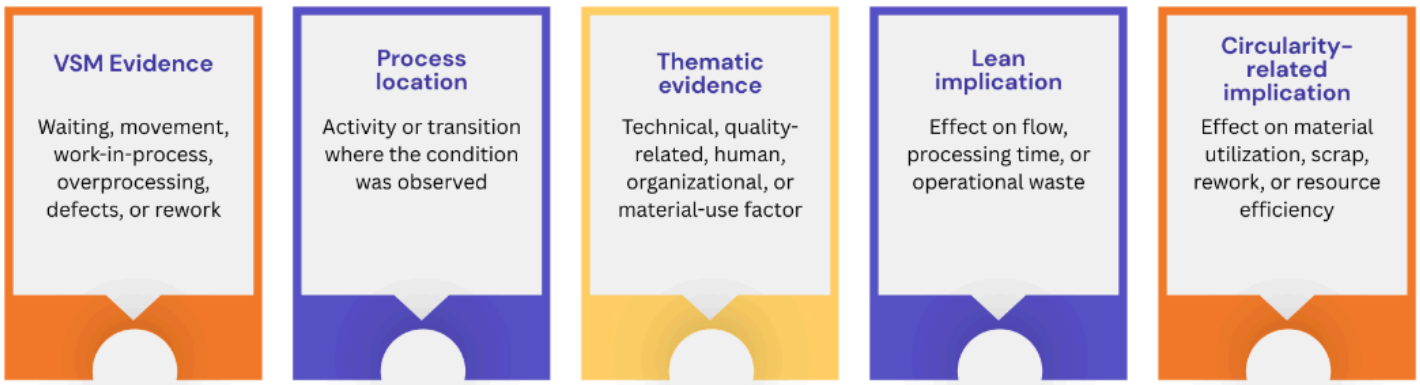


Figure 1

Integrating VSM and thematic findings

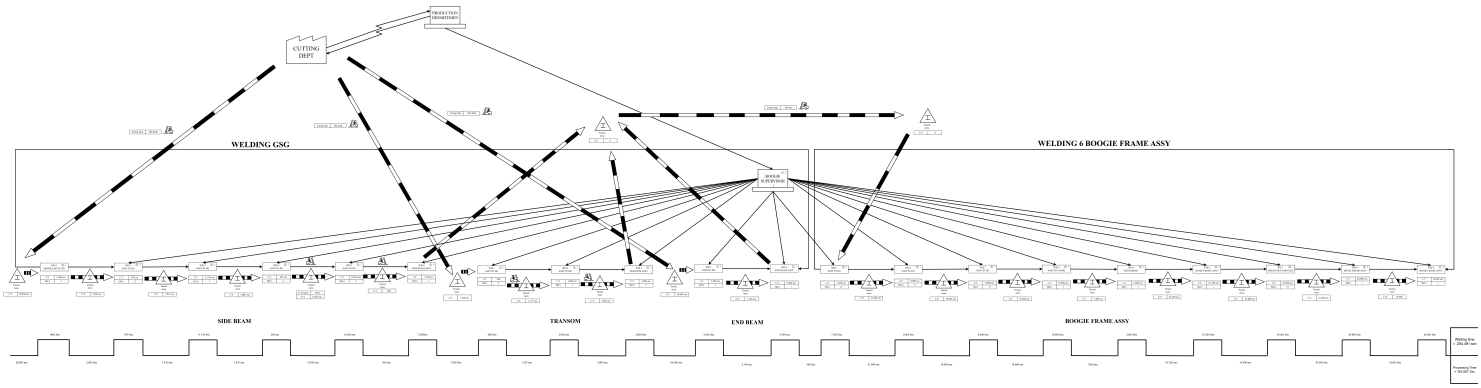


Figure 2

Current State Value Stream Mapping Welding Process

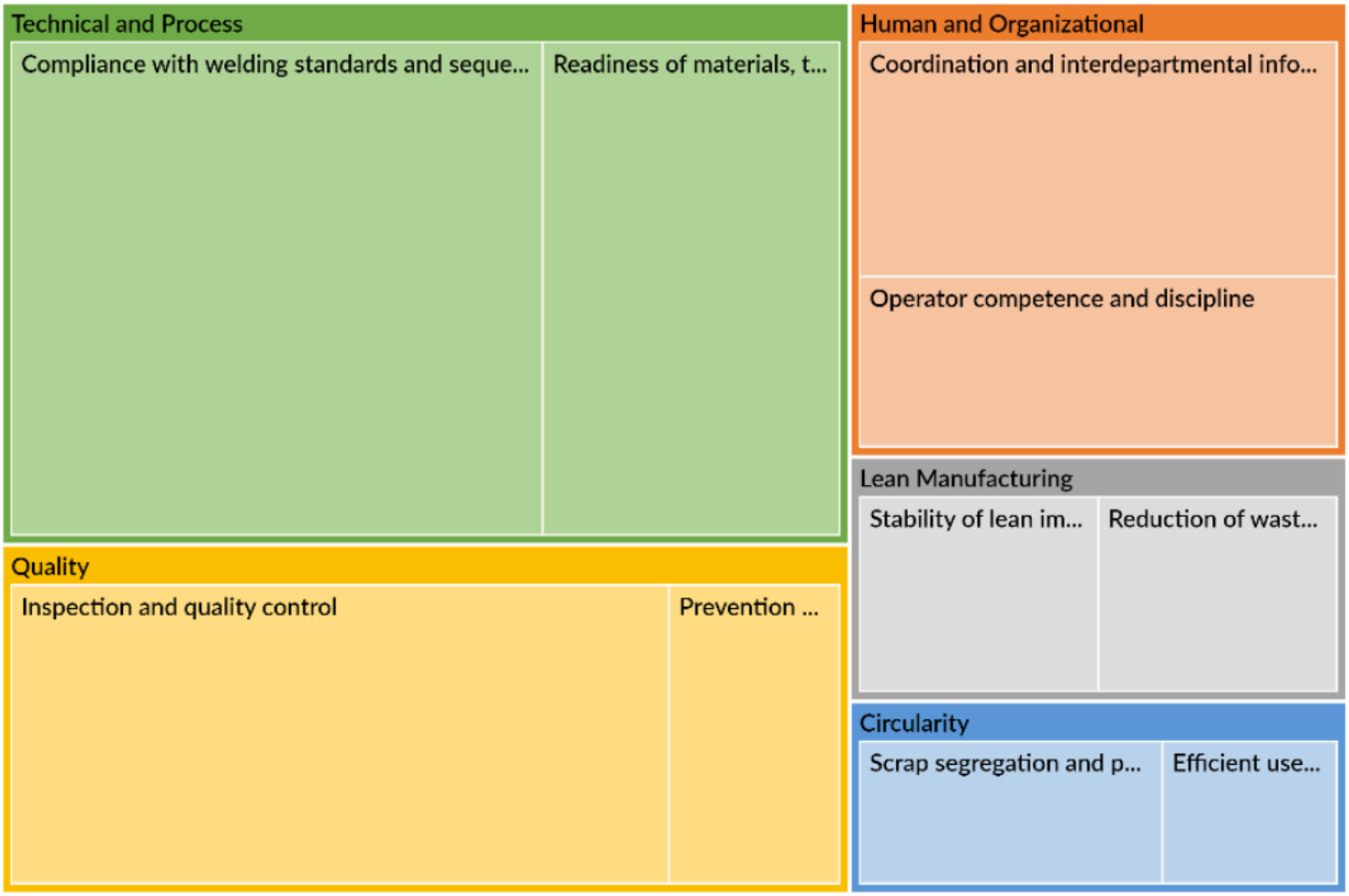


Figure 3

Treemap of Lean-Circular themes generated through NVivo coding.

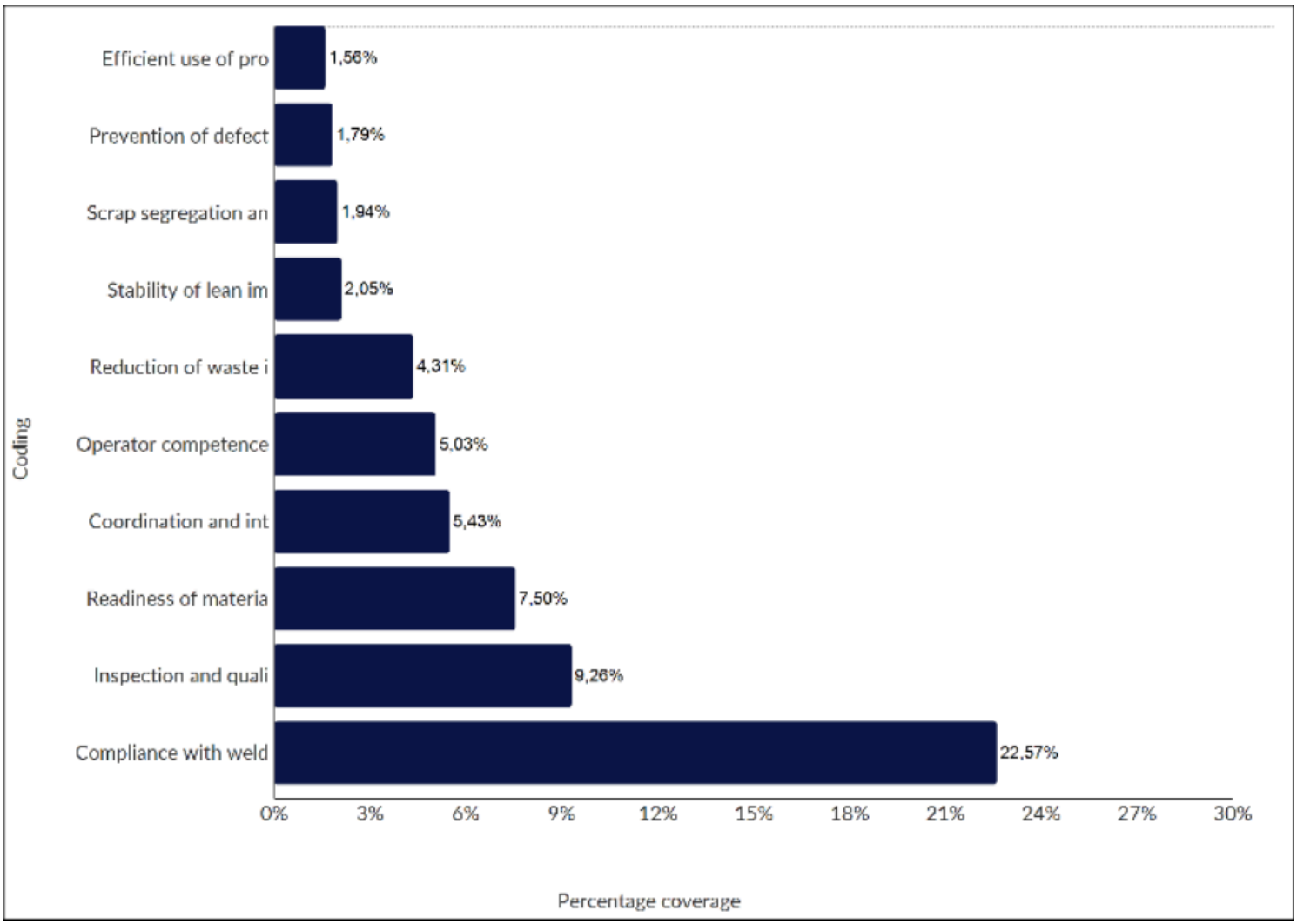


Figure 4

Distribution of coding references across categories in the interview dataset.