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Occupational Health and Safety Risk Assessment in Mechanized Waste Processing Operations Using Failure Mode and Effect Analysis

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ABSTRACT: Mechanized waste processing facilities present elevated occupational safety risks due to intensive interaction between workers and rotating machinery. This study assessed occupational safety risks in the mechanized sorting, shredding, and compaction stages at an Integrated Solid Waste Treatment Facility (TPST X) producing Refuse-Derived Fuel (RDF) in Cimahi City, Indonesia, using the Failure Mode and Effect Analysis (FMEA) technique. Employing a descriptive analytical study design, data were collected through direct observation, in-depth interviews with 24 informants, and document review. Failure modes were identified for each machine-based process, and Risk Priority Numbers (RPN) were calculated from the product of severity, occurrence, and detection scores. A total of 37 failure modes were identified across eight machine categories: conveyor systems, magnetic separator, turbo separator, gibrik, shredder, centris, crusher, and ball press. Four failure modes were classified as very high risk (RPN ≥ 181), with the three highest values (RPN = 240 each) associated with noise exposure in the turbo separator, gibrik, and centris work areas.

KEYWORDS: Risk assessment; occupational health and safety; waste management; RDF facility; FMEA

1. Introduction

The global transition toward sustainable waste management has increased the development of mechanized waste-processing facilities. Integrated Solid Waste Treatment Facilities (TPST) are designed to sort, process, and convert mixed municipal solid waste (MSW) into useful products such as RDF. RDF production involves several mechanized processes, including waste sorting on conveyor belts, magnetic separation, shredding, turbo separation, and compaction. During these operations, workers interact closely with machinery and are exposed to biological, chemical, physical, and toxic hazards present in municipal waste. Material recovery facilities (MRFs) have been associated with high rates of struck-by-object and caught-in-equipment injuries [1]. The mixed and unpredictable nature of incoming waste can disrupt operations when non-target materials such as textiles, ropes, thick plastics, and metal objects enter processing equipment. These materials often cause machine-jamming events, requiring workers to perform manual clearing activities near moving machine parts. Without proper energy isolation procedures, workers may be exposed to entanglement, crushing, and ejection hazards that can result in serious injuries [2].

Despite these hazards, occupational health and safety (OHS) risk assessment studies focusing on mechanized waste-processing operations in Indonesian TPST facilities remain limited. Previous studies in Indonesia have mainly focused on landfill operations and waste collection workers, while systematic quantitative assessments of machine-related risks are still scarce [3–6]. This gap limits the ability of facility managers to identify priority risks and allocate resources effectively. Failure Mode and Effects Analysis (FMEA) is a widely used risk assessment method that helps identify identify and prevent potential failures in a product, design, or process before they occur, and risk prioritization. Risks are then prioritized using the Risk Priority Number (RPN), which is calculated from severity (S), occurrence (O), and detection (D) scores [7]. Therefore, this study aimed to: (1) identify potential failure modes in the mechanized process at TPST X; (2) assess risk levels using FMEA-based RPN calculations; By focusing on machine-based processing stages, this study provides risk information that can support safety management at TPST X and contribute to the development of OHS guidelines for mechanized waste-processing facilities.

2. Materials and Methods

2.1. Study setting and design.

This study employed a descriptive analytical design and was conducted from April to May 2026 at TPST X in Cimahi City, West Java, Indonesia. TPST X is designed to process 50 tons of mixed domestic waste per day into recyclables, biomass, and RDF (a biomass-fluff blend). The facility operates machine lines comprising eight main machine types: conveyor feeder, conveyor flat, magnetic separator, turbo separator, gibrik screw (organic shredder, shredder with *centris* dryer, crusher, and ball press. The scope was delimited to three mechanized processing stages: (1) waste sorting (conveyor flat and magnetic separator); (2) waste shredding and separation (turbo separator and gibrik screw conveyor); and (3) waste shredding, crushing, and compaction (shredder, *centri*s, blower, crusher, and ball press).

2.2. Participants.

The study involved 24 informants, consisting of 22 workers from TPST X, one coordinator of the TPST Cimahi City, and one waste management expert who was involved in the development of the facility's standard operating procedures (SOPs) for waste processing. Informants were selected using purposive sampling based on their direct involvement in operational activities and their technical knowledge of the waste-processing system.

2.3. Data collection.

This study used both primary and secondary data. Primary data were gathered through direct observations of the waste-processing workflow and interviews with 24 participants, including workers, the TPST coordinator, and waste management expert. These interviews offered insights into work processes, hazards, failure modes, and occupational incidents. Secondary data came from internal TPST X documents, including flow diagrams, Standard Operating

Procedures (SOPs), technical specifications, and equipment maintenance records. This information was essential for identifying failure causes and control measures in the Failure Mode and Effects Analysis (FMEA) assessment.

2.4. FMEA and RPN calculation.

Generally, each risk factor can be measured with 10 rating levels from 1 to 10. For instance, Table 1 shows the applied criteria of rating for the severity S of a failure in FMEA. Similarly, the occurrence (O) and the detectability (D) of failure. More details can be found in [8−10].

Table 1. Applied criteria of rating for severity.

Rating	Effect on system	Injury criteria
1	No effect on system performance	No injury or first aid only (First aid)
2	Negligible effect on system performance	Medical treatment required; no lost workdays
3	Minor effect on system performance	Absence <3 days; the worker returns in full health
4	Low effect on product/system; minor rework required	Absence >3 days to <3 weeks
5	Moderate effect on system performance; rework required	Absence >3 weeks; worker recovers fully
6	Significant degradation of system performance	Absence >3 weeks; health condition still recoverable
7	Major effect; system likely inoperable	Minor permanent disability (e.g., partial digit impairment)
8	Extreme effect: the system loses its primary function and cannot operate	Serious irreversible disability
9	Serious failure involving regulatory violation	Severe injury: stroke, paralysis, blindness, or amputation
10	Hazardous failure without warning; operations halted; regulatory breach	Fatality

While severity reflects the potential consequences of a failure mode, the likelihood of its occurrence must also be considered to evaluate overall risk. Therefore, the occurrence rating was used to estimate the frequency with which a failure mode was expected to occur under normal operating conditions, as shown in Table 2.

Table 2. Applied criteria of rating for occurrence.

Score	Occurrence	Description
1	Once every 5 years	Very rare; unlikely to occur under normal operating conditions
2	Once per year	Rare; occasionally observed over a multi-year period
3	Once per month	Occasional; occurs monthly
4	Once per week	Moderate; recurs weekly during standard operations
5	Once per 8-hour shift	Frequent; expected to occur at least once per work shift
6	Once per hour	High; occurs routinely within each working hour
7	Once per 30 minutes	Very high; occurs multiple times per hour
8	Once per minute	Very high; near-continuous occurrence
9	Once per 30 seconds	Extremely high; occurs almost continuously
10	Permanent / continuous	Inevitable; failure mode is always present

In addition to severity and occurrence, FMEA considers the effectiveness of existing controls in identifying failures before adverse consequences occur. Table 3 presents the detection rating criteria used to assess the probability that a failure mode would be detected through existing preventive or monitoring measures. RPN scores were classified into five risk categories, as defined in Table 4. Scores from 1 to 15 indicate very low, while scores from 181 to 1000 represent very high risk requiring immediate corrective action. This classification provides a basis for prioritizing risk mitigation measures across the assessed failure modes.

Table 3. Applied criteria of rating for detection.

Rating	Detection likelihood	Description
1	Almost certain	Detection controls will almost certainly identify the failure mode
2	Very high	Very high probability that existing controls will detect the failure
3	High	High probability of detection through established controls
4	Moderately high	Moderately high chance of detection; some uncertainty remains
5	Moderate	Moderate chance of detection; control effectiveness is variable
6	Low	Low probability of detection; controls are unreliable
7	Very low	Very low probability; detection is not consistently achieved
8	Rare	Rarely detected; controls are largely ineffective
9	Very rare	Existing controls are unlikely to detect the failure
10	Almost impossible	No known control capable of detecting the failure mode

Table 4. Risk priority number scale.

RPN Score	Risk Categories
181-1000	Very High
91-180	High Risk
31-90	Moderate
16-30	Low Risk
1-15	Very low risk

3. Results and Discussion

3.1. Overview mechanized processing stage.

The RDF production process at TPST X consists of three main mechanized stages: (1) waste sorting, (2) shredding and separation, and (3) shredding, crushing, and compaction. These interconnected stages are designed to process mixed municipal solid waste into biomass and fluff as the primary components of RDF, while requiring continuous interaction between workers and processing equipment. Based on field observations, interviews with operators, supervisors, maintenance personnel, and facility management, as well as document review, workers perform machine operation, monitoring, inspection, cleaning, and troubleshooting activities throughout the processing line. In Stage 1, workers manually sort recyclable materials on a moving conveyor before the residual waste passes through a magnetic separator. During this activity, workers are exposed to biological hazards from mixed waste and physical hazards from sharp objects concealed within the waste stream. In Stage 2, workers monitor the turbo separator and associated conveyor systems, where machine-jamming events frequently occur due to the presence of non-target materials such as textiles, ropes, thick plastics, and metal wires. In Stage 3, workers operate, inspect, and clean shredding, crushing, and compaction equipment, exposing them to rotating machinery, noise, dust, electrical hazards, and potential entanglement hazards.

Field observations and interviews indicated that machine-jamming events occurred regularly across all processing stages and often required manual clearing using wooden or metal rods. Existing controls included personal protective equipment, warning signs, emergency stop buttons, routine inspections, and machine guarding on selected equipment. However, no formal lockout-tagout (LOTO) procedure, automated jam-detection system, or documented abnormal-condition response procedure was identified during the study period. These operational conditions formed the basis for the identification of failure modes and the subsequent FMEA-based risk assessment.

3.2. Risk assessment by process stage.

To provide an overview of occupational risk distribution across the RDF production process, the identified failure modes were grouped according to operational stage and risk level. Table

5 summarizes the distribution of 37 failure modes across the three mechanized processing stages based on their Risk Priority Number (RPN) categories.

Table 5. Distribution of failure modes by process stage and risk level.

Process Stage	Very High (≥181)	High (91–180)	Moderate (31–90)	Low (16–30)	Very Low (<16)	Total
Stage 1: Waste Sorting		6	1			7
Stage 2: Shredding & Separation	1	6	3			10
3a. Shredding & Compaction Organic sub-line (Gibrik, Ballpress)	2	4	3	1		10
3b. Shredding & Crushing Inorganic sub-line (Shredder, Centris, Crusher)	1	5	4			10
Total (all three stages)	4	21	11	1		37

The distribution of failure modes by process stage and risk level shows that most identified failure modes were classified as high risk (n = 21), followed by moderate risk (n = 11), very high risk (n = 4), and low risk (n = 1), while no failure modes were categorized as very low risk. The distribution of risks was uneven across operational stages, with all very high-risk failure modes concentrated in Stage 2 (Shredding and Separation) and Stage 3 (Shredding, Crushing, and Compaction). In contrast, Stage 1 (Waste Sorting), resulted in only high- and moderate-risk failure modes, suggesting that interactions between workers and mechanized equipment are the primary source of occupational risk at TPST X. This finding highlights the need to prioritize this stage for control measures and detailed risk assessment.

3.2.1. Stage 1: waste sorting.

The waste sorting stage involved manual sorting activities on the conveyor flat and the operation of the magnetic separator. To identify specific occupational hazards during this stage, each operational activity was evaluated using FMEA. Table 6 presents the identified failure modes, potential effects, and corresponding RPN values for the waste sorting stage. The highest RPN values were associated with biological exposure from mixed waste (RPN = 144). The elevated RPN assigned to biological exposure reflects the continuous interaction between workers and mixed municipal waste throughout the work shift. Unlike mechanical hazards that are often visible, biological contaminants are difficult to identify before exposure occurs. Similar findings have been reported in international waste-sorting facilities, where workers are exposed to pathogenic bacteria, fungi, and other bioaerosols associated with respiratory symptoms and inflammatory responses [11−13]. Eriksen et al. identified several human pathogens in waste-sorting bioaerosols, while Szulc et al. reported high levels of microbial contamination in sorting environments [11, 12]. Consistent with these studies, the high RPN observed in the present study was driven by frequent exposure and limited detectability, highlighting the need for improved source segregation, ventilation, biological exposure monitoring, and appropriate respiratory protection.

Table 6. Failure modes and RPN - Stage 1: waste sorting.

No.	Sub-Process	Failure Mode	Failure Effect	S	O	D	RPN
1.	Component inspection (conveyor flat & magnetic separator)	Machine components in abnormal/damaged condition were not identified pre-shift	Conveyor disruption; worker struck by a detached moving component	4	4	6	96
		The emergency stop does not function during an emergency	The machine cannot be halted rapidly; risk of serious injury or amputation	7	2	8	112
2.	Sorting of MDU & residue on the conveyor flat	Sharp/hazardous waste objects are present on the conveyor belt	Lacerations, puncture wounds, and contaminated injuries from sharp objects	3	5	8	120
		Biological and chemical hazard exposure from mixed waste	Pathogen infection (respiratory, dermal	3	6	8	144
3.	Magnetic separator operation	Sharp ferrous scrap falls from the collection tray	Laceration or puncture injury to nearby workers	3	5	4	60
		Ferrous metal passes the magnetic separator	Technical disruption in the downstream separation process	4	5	5	100
4.	Shutdown conveyor flat & magnetic separator	Machine not fully stopped when cleaning begins	Entanglement in moving components during cleaning	7	2	8	112

Contact with sharp materials on the conveyor belt also resulted in a high RPN value (RPN = 120), reflecting the frequent handling of mixed waste during manual sorting activities. Workers may encounter broken glass, metal fragments, razor blades, and improperly discarded medical sharps that are often concealed within waste streams and difficult to identify before direct contact occurs. Similar findings have been reported in municipal waste-management systems, where cuts, punctures, and needlestick injuries are among the most common occupational injuries associated with mixed waste handling [14, 15]. Studies have shown that household-generated sharps, including needles and lancets, are frequently disposed of in general waste streams, increasing injury and infection risks for waste workers [15]. Consistent with these findings, the elevated RPN in the present study was driven by the high frequency of worker exposure and the limited detectability of sharp hazards prior to contact, highlighting the importance of source segregation, puncture-resistant gloves, and worker awareness programs.

Emergency-stop malfunction was also identified as a high-risk failure mode (RPN = 112) because workers rely on emergency-stop systems to immediately halt machinery during abnormal conditions. The literature provides limited evidence on the reliability of emergency-stop systems in waste-processing facilities. However, research from industrial settings has shown that safety shutdown systems may become ineffective due to hidden failures, insufficient maintenance, or bypassed safeguards, potentially increasing the severity of machinery-related incidents [16]. In the present study, the elevated RPN was driven by high severity and limited detectability, as hidden failures may remain unnoticed until an emergency occurs. These findings highlight the importance of routine inspection, functional testing, and preventive maintenance of emergency-stop systems.

3.2.2. Stage 2: shredding & separation.

Following waste sorting, materials entered the shredding and separation stage, which involved the turbo separator and associated conveyor systems. This stage introduced additional hazards related to machine operation, waste accumulation, and material-flow disruption. Table 7 summarizes the identified failure modes and corresponding RPN values for this operational stage.

Table 7. Failure modes and RPN P – Stage 2: shredding & separation.

No.	Sub-Process	Failure Mode	Failure Effect	S	O	D	RPN
1	Component inspection (turbo separator & conveyor)	Loose components (bolts, bearings, pulleys) not identified pre-shift	Unstable machine rotation; worker struck by detached rotating part	4	4	6	96
2	Turbo separator start-up	Electrical insulation failure on panel cables (stripped/exposed)	Short-circuit; electric shock; sudden machine shutdown	4	2	8	64
		The emergency stop fails to function during an abnormal condition	The machine cannot be halted; risk of fatal entanglement or crush	7	2	8	112
3	Feeding waste into the turbo separator	Non-target materials (textiles, ropes, thick plastics, metal) enter the separation system	Machine jamming; manual intervention near active rotor; process stoppage	5	6	5	150
		Excess waste accumulation on the separator screen	Disrupted separation; the worker performs manual clearing near the screen	5	6	5	150
		Waste falls from the conveyor onto the operator's work area	Impact injury; slipping hazard; increased biological pathogen exposure	5	4	5	100
4	Turbo separator operation	Machine jamming during the separation process	Operator clears jam manually near active rotor; severe entanglement risk	5	6	4	120
		The inspection window opens without mechanical support	The worker’s hand/arm could be trapped in the machine mechanism during access	4	3	6	72
		Waste ejected from the machine during separation	Worker struck by ejected material; eye and face injury	3	6	5	90
		Noise exposure at the turbo separator work area	Reduced work concentration; long-term hearing damage	5	6	8	240

As shown in Table 7, noise exposure at the turbo separator work area generated the highest RPN value (RPN = 240), followed by non-target material ingress and excessive waste accumulation within the separation system (RPN = 150). These findings indicate that both chronic occupational health hazards and operational disruptions contribute substantially to overall risk. The high RPN associated with noise exposure resulted from frequent worker exposure and the limited ability of existing controls to detect long-term hearing damage before adverse effects occur. Meanwhile, machine-jamming-related failure modes received elevated RPN values because prohibited materials such as textiles, ropes, and metal objects frequently entered the system, disrupting operations and requiring manual intervention near rotating components. This pattern has also been observed in mechanized waste-processing facilities internationally, where equipment blockage is recognized as a major contributor to maintenance-related injuries. This finding aligns with studies identifying equipment blockage, jam-clearing, and maintenance activities as major causes of machinery-related injuries [17, 18]. Severe incidents often occur when workers remove foreign materials or clear blockages near moving machine parts without adequate guarding or hazardous energy controls [17]. Similar hazards have been reported across mechanized industries, where conveyors, rotating shafts, rollers, and shredders create entanglement, crushing, and drawing-in risks during cleaning, maintenance, and unjamming tasks [15, 19].

In the present study, machine jams were primarily caused by prohibited materials entering the waste stream rather than equipment failure. Workers frequently used rods to remove accumulated waste and restore material flow, exposing them to hazards associated with non-routine tasks [18]. Previous studies have also shown that injuries commonly occur when lockout procedures are not properly implemented before maintenance or unjamming activities [20]. Although this study assessed risks prospectively using FMEA rather than accident records, both approaches highlight the same underlying factors: exposure to moving machinery, inadequate safeguarding, and reliance on manual jam-clearing [17, 19]. The recurrence of machine-jamming events across multiple processing stages indicates a systemic hazard. Therefore, risk reduction should focus on engineering controls, including improved machine guarding, interlocked access systems, automated jam detection, and LOTO procedures, supported by worker training and standardized response protocols [21].

3.2.3. Stage 3: shredding, crushing & compaction.

The final mechanized processing stage consisted of two operational sub-lines: the organic processing line and the inorganic processing line. Due to differences in equipment configuration and waste characteristics, each sub-line was analyzed separately. Table 8 presents the FMEA results for the organic processing line. The highest Risk Priority Number (RPN) values in the organic processing line were associated with noise exposure in the gibrik work area (RPN = 240) and the entry of prohibited materials into the shredding system (RPN = 196). These failure modes were primarily driven by high occurrence rates and insufficient preventive controls. The findings indicate that occupational health risks and inadequate waste segregation represented the most critical issues within the organic processing line and therefore require priority corrective actions. Noise exposure at the gibrik work area produced the highest RPN because the equipment operated continuously throughout the processing cycle, exposing workers to prolonged periods of elevated noise levels. In addition to the potential for hearing impairment, excessive noise may reduce worker concentration, interfere with communication, and limit the ability to detect warning signals or abnormal machine conditions. Consequently, this hazard can indirectly increase the likelihood of operational errors and workplace accidents. The entry of prohibited materials, such as textiles, ropes, sacks, thick plastics, and metal objects, into the shredding system represented the second most critical failure mode. The mixed nature of municipal waste makes complete separation difficult, increasing the probability that unsuitable materials enter the processing line. Such materials can damage blades and screens, reduce processing efficiency, and create safety hazards when fragments are ejected during operation. Similarly, machine-jamming events (RPN = 175) were closely related to the presence of inappropriate waste materials and often required manual intervention by workers near active equipment, thereby increasing the risk of injury.

Table 8. Failure modes and RPN - Stage 3: organic sub-line (Gibrik screw, screw conveyor, ball press).

No.	Sub-Process	Failure Mode	Failure Effect	S	O	D	RPN
1	Component inspection (gibrik & screw conveyor)	Loose machine components not identified pre-shift	Unstable rotation; worker struck by detached component	4	4	6	96
2	Gibrik screw start-up	Electrical components operated in an unsafe condition	Short-circuit; electric shock risk to the operator	7	2	8	112
		The emergency stop cannot be used in abnormal conditions	The machine cannot be halted; increased risk of serious injury	7	2	8	112
3	Organic waste feeding to gibrik	Textiles, thick plastics, ropes, sacks, and metal enter the shredding system	Blade and screen damage; worker struck by ejected metal fragments	4	6	5	196
	Gibrik screw operation	Machine jam during shredding	Flow halted; worker intervenes manually near active blades using improvised rod tools	4	6	5	175
		Waste ejected from the screen/blade area	Eye and face injury from projectile waste fragments	3	6	5	90
		Noise exposure at the Gibrik work area	Hearing damage, impaired communication, and reduced hazard awareness	5	6	8	240
4	Ball press operation	Leachate does not drain adequately during pressing	Slippery work area; worker exposed to biological leachate contamination	2	3	4	24
		The ball press slider movement unstable during pressing	Suboptimal compaction; worker at risk during manual handling near the press zone	3	3	5	45
5	Shutdown gibrik & screw conveyor	The machine is cleaned while the electrical energy or moving parts are still active	Worker risks electric shock or entanglement in residually moving components	4	2	4	32

The inorganic processing line consisted of the shredder, centris, and crusher systems, which introduced additional hazards related to dust generation, machine blockage, and continuous equipment operation. As presented in Table 9, noise exposure in the centris work area generated the highest RPN value (RPN = 240), followed by excessive airborne fluff dust (RPN = 144) and shredder-jamming events (RPN = 120). These results suggest that both occupational health hazards and machine-related safety issues were major contributors to the overall risk profile of the inorganic processing line. Consequently, improvements in noise control, dust mitigation, and equipment maintenance should be prioritized to reduce operational risks. The prominence of noise exposure as the highest-ranked hazard is consistent with previous studies that mechanized waste-processing facilities frequently generate noise levels exceeding the occupational exposure limit of 85 dB(A) due to the operation of shredders, conveyors, compactors, and other heavy equipment [17, 22]. Kaliakatsos et.al., reported noise levels in waste-sorting facilities reaching up to 89.3 dB(A) [22]. Other studies conducted in Greece and China identified elevated rates of noise-induced hearing loss (NIHL) among waste workers, with risk increasing according to exposure intensity and duration [23, 24]. In the present study, the high RPN associated with noise exposure was primarily driven by its frequent occurrence and the cumulative nature of hearing damage, which often develops gradually and remains undetected until significant impairment has occurred.

Table 9. Failure modes and RPN - Stage 3: inorganic sub-line (shredder, centris, crusher).

No.	Sub-Process	Failure Mode	Failure Effect	S	O	D	RPN
1	Component inspection (shredder, centris, crusher)	Machine components in abnormal condition were not identified pre-shift	Unstable machine rotation; worker struck by detached component	7	2	8	112
2	Shredder, centris, crusher start-up	MCCB or electrical panel operated in an unsafe condition	Short-circuit; electric shock risk	7	2	8	112
		The emergency stop cannot be used in abnormal conditions	The machine cannot be halted rapidly; there is an increased risk of serious injury	7	2	8	112
3	Feeding inorganic waste to the shredder	Shredder jams during the shredding operation	Material flow halted; the worker clears the jam manually near rotating blades without energy isolation	4	6	5	120
		Waste ejected from the shredder area	Screw conveyor guard removed; worker struck by ejected fragments; entanglement risk	3	6	5	90
4	Centris & blower operation	Waste blockage at *centris* or blower	Material flow to the stage halted; the worker clears the blockage near the rotating centris components	5	5	3	75
		Noise exposure at *centris* work area	Hearing damage; impaired communication; reduced hazard perception	5	6	8	240
5	Stage and crusher flow regulation	Excessive airborne fluff dust in the operator's work area	Respiratory hazard; distraction near active crusher	3	6	8	144
		The crusher stops suddenly without an early warning indication	Worker reaches into active crusher zone to clear jam; severe laceration and crush risk	5	4	4	90
6	Cleaning/shutdo wn	Machine cleaned without LOTO; components re-energize during cleaning	Electric shock; entanglement in restarted component	4	2	4	32

Previous research has also linked noise exposure with reduced concentration, impaired communication, and diminished hazard awareness, thereby increasing the possibility of workplace accidents in environments utilizing moving machinery [25]. Although previous studies have predominantly focused on exposure assessment and hearing-loss prevalence [22−24], the present FMEA framework demonstrates that occupational noise should be considered a critical operational risk. The consistently elevated RPN values emphasize the need for comprehensive noise-control strategies, including engineering controls, routine noise monitoring, hearing conservation programs, and mandatory use of hearing protection.

4. Conclusions

This study applied Failure Mode and Effects Analysis (FMEA) to assess occupational health and safety risks across mechanized waste-processing operations at an RDF-producing TPST X in Cimahi City, Indonesia. A total of 37 failure modes were identified across waste sorting, shredding and separation, and shredding, crushing, and compaction processes. Four failure modes were classified as very high risk (RPN ≥181), with the highest RPN values associated with noise exposure in the turbo separator, gibrik, and centris work areas. The findings indicate that occupational risks are primarily driven by worker interaction with processing equipment, machine-jamming events caused by non-target materials, and limited hazard detection mechanisms. These results highlight the importance of prioritizing engineering controls, such as machine guarding, automated jam-detection systems, dust-control measures, and noise-reduction technologies, supported by administrative controls including preventive maintenance, machine-specific procedures, and LOTO implementation. This study was limited to a single facility and did not include quantitative exposure measurements. Future research should incorporate environmental and personal exposure monitoring and involve multiple waste-processing facilities to strengthen occupational risk assessment and control strategies in mechanized waste-management operations.

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Author Contribution

Ulfa Alfiani Nadillah: Conceptualization, Methodology, Data Collection, Data Analysis, Writing, Mila Tejamaya: Conceptualization and Supervision, Annisa Dwi Safiyanti: Data Analysis and Writing.

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