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Redesigning a Hazardous Waste Storage Facility to Improve Compliance and Safety in a Plastic Packaging Company in Bekasi Regency

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Abstract
This study evaluates critical non-compliances in the Temporary Storage Facility for Hazardous and Toxic Waste (TPS LB3) at a plastic packaging manufacturer in West Java, Indonesia. The assessment was conducted in accordance with Government Regulation No. 22 of 2021, Ministry of Environment and Forestry Regulation No. 6 of 2021, and relevant Indonesian National Standards (SNI). A descriptive engineering design approach was applied, integrating gap analysis, qualitative risk assessment using a 5×5 risk matrix, and Computer-Aided Design (AutoCAD 2024). Key deficiencies identified include insufficient spill containment capacity (0.015 m^3 vs. 0.22 m^3), improper drainage of emergency eyewash to stormwater systems, inadequate aisle width (10 cm vs. 60 cm standard), and unsafe co-storage of incompatible waste types. The proposed redesign (10.5 m × 6.06 m) addresses these issues through an 8-meter drainage system, a 0.225 m^3 containment basin, ANSI Z358.1-compliant eyewash installation, improved layout with proper spacing and zoning, and verified ventilation and lighting systems. The redesigned facility is capable of safely accommodating a peak waste accumulation of 4.566 tons within a 90-day storage period while meeting regulatory compliance.
Keywords: *facility redesign; hazardous waste; regulatory compliance; risk assessment; temporary hazardous storage facility*

Abstrak
Penelitian ini mengevaluasi ketidaksesuaian kritis pada Tempat Penyimpanan Sementara Limbah Bahan Berbahaya dan Beracun (TPS LB3) di industri kemasan plastik di Jawa Barat, Indonesia. Evaluasi dilakukan berdasarkan Peraturan Pemerintah No. 22 Tahun 2021, Peraturan Menteri LHK No. 6 Tahun 2021, serta Standar Nasional Indonesia (SNI). Metode yang digunakan adalah pendekatan desain rekayasa deskriptif melalui analisis kesenjangan, penilaian risiko kualitatif dengan matriks 5×5, serta perancangan berbasis Computer-Aided Design (AutoCAD 2024). Hasil analisis menunjukkan beberapa ketidaksesuaian utama, antara lain kapasitas bak penampung tumpahan yang tidak memadai (0,015 m^3 dibandingkan 0,22 m^3), sistem pembuangan eyewash yang tidak sesuai, lebar lorong yang kurang dari standar (10 cm dibandingkan 60 cm), serta pencampuran limbah yang tidak kompatibel. Desain ulang yang diusulkan dengan ukuran 10,5 m × 6,06 m mengatasi seluruh permasalahan melalui sistem drainase sepanjang 8 meter, bak penampung 0,225 m^3, pemasangan eyewash sesuai standar ANSI Z358.1, penataan ulang zona penyimpanan, serta perbaikan ventilasi dan pencahayaan. Fasilitas hasil redesign mampu menampung akumulasi limbah hingga 4,566 ton selama periode penyimpanan 90 hari sesuai regulasi.
Kata Kunci: *desain ulang fasilitas; kepatuhan regulasi; limbah lb3; penilaian risiko; tempat penyimpanan sementara b3*

1. Introduction

The plastic packaging manufacturing sector constitutes a critical component of Indonesia's industrial supply chain, supporting fast-moving consumer goods, food, and pharmaceutical industries. The production processes characteristic of this sector including flexographic and gravure printing, injection and blow molding, equipment maintenance, and solvent-based cleaning invariably generate diverse hazardous and toxic waste streams (Limbah Bahan Berbahaya dan Beracun/ LB3). These streams, encompassing organic solvents, used lubricating oils, contaminated absorbent materials, electronic components, and chemical residues, present substantial risks to environmental sustainability and occupational health if not systematically managed within a compliant infrastructure [1][2]. Hazardous waste management in Indonesia is governed by a hierarchical regulatory framework. Government Regulation No. 22 of 2021 (PP

No. 22/2021) [2] establishes the overarching legal basis for environmental protection and B3 waste management, while PermenLHK No.6/2021 [3] provides technical requirements for every stage of the B3 lifecycle, from generation and storage through treatment, transportation, and final disposal. Within this lifecycle, the Temporary Storage Facility for Hazardous Waste (TPS LB3) functions as the initial and most operationally immediate control point, and its design directly determines the safety, regulatory compliance, and environmental integrity of a facility's overall waste management system [4].

Empirical evaluations conducted across industrial areas in West Java consistently reveal persistent and systemic non-compliance in TPS LB3 facilities. Recurring deficiencies include inadequate secondary containment systems, improper emergency response equipment, unsafe spatial configurations, and the absence of rigorous waste segregation protocols [4], [5]. These deficiencies are frequently attributable to a foundational gap in design practice: the absence of an integrated engineering approach that simultaneously satisfies regulatory technical specifications, risk mitigation imperatives, and operational logistics requirements [6].

PT X, a plastic packaging manufacturing company in the Cibitung industrial zone of West Java, generates approximately 1.522 tons of LB3 waste per month. A comprehensive field evaluation of the existing TPS LB3 facility revealed eight distinct categories of regulatory non-compliance, including a critically undersized spill containment basin (0.015 m^3 actual vs. 0.22 m^3 required a 93.2% deficiency), an improperly drained emergency eyewash station, aisle widths of only 10 cm, and the dangerous co-location of flammable and toxic waste without physical segregation. The cumulative effect of these deficiencies creates significant risks of environmental contamination, occupational injury, and regulatory sanction [7], [14]. Previous scholarly work on hazardous waste facility management has addressed risk assessment methodologies [7] and layout optimization techniques [8] as discrete areas of inquiry. However, these approaches have been applied in isolation, yielding solutions that address individual compliance parameters without capturing the systemic interdependencies between containment design, spatial layout, emergency systems, and operational workflow [16]. The absence of a unified, evidence-based engineering framework that integrates these elements within the specific context of Indonesian regulatory requirements represents a critical gap in the applied environmental engineering literature [9][10].

This study addresses this gap by developing a comprehensive, integrated engineering redesign method for the TPS LB3 facility at PT X. The specific objectives are: (i) to systematically identify and quantitatively characterize all regulatory non-compliances through a structured Gap Analysis against PermenLHK No.6/2021 [3] and PP No. 22/2021 [2]; (ii) to assess and prioritize associated environmental and occupational health risks through a qualitative 5×5 risk matrix; and (iii) to develop a validated, CAD-based facility redesign that achieves full compliance with applicable Indonesian standards while optimizing operational safety, material handling efficiency, and 90-day storage capacity.

2. Research Methods

2.1 Research Design

This study employed a descriptive engineering design approach, structured into three sequential and iterative phases. In the first phase, the existing TPS LB3 facility was subjected to a comprehensive condition evaluation through direct field observation and physical measurement. In the second phase, a systematic identification and quantification of regulatory non-compliances and associated operational risks was conducted using structured analytical tools. In the third phase, the findings were synthesized into an optimized facility redesign developed using AutoCAD 2024 [10].

2.2 Data Collection

Primary data were gathered through direct field observations and precise physical measurements of the TPS LB3 structural dimensions, including total floor area, gutter system length and slope angle, spill basin volume (measured by volumetric displacement), internal aisle widths, wall clearances, and the precise location and drainage pathway of the emergency eyewash station. Calibrated laser distance meters and graduated measuring tapes were used as measurement instruments, and photographic documentation was systematically conducted to provide a verifiable visual record.

Secondary data were compiled from PT X's internal operational records, including monthly LB3 waste generation logs, hazardous waste transport manifests (Manifest LB3), and existing facility layout drawings maintained by the Environmental, Health, and Safety (EHS) department. Indonesian national regulatory documents, specifically PP No. 22/2021 [2], PermenLHK No.6/2021 [3], SNI 03-6572-2001 [4], and SNI 03-6575-2001 [5], were used as the primary normative references for all compliance evaluations.

2.3 Data Analysis Techniques

a) Gap Analysis

The gap analysis constituted the primary diagnostic instrument of this study. Each measurable physical parameter of the existing TPS LB3 facility was systematically compared against the specific quantitative requirements stipulated in the applicable regulatory articles. Discrepancies were documented, categorized by compliance parameter, and quantified where possible (e.g., capacity deficiency expressed as a percentage). The gap analysis was structured to encompass eight distinct compliance dimensions, including spill containment capacity, aisle geometry, waste segregation, emergency systems, ventilation, lighting, signage, and 90-day storage capacity planning [9]. For each dimension, the applicable regulatory reference (article number and regulation) was explicitly cited to ensure traceability.

b) Risk Assessment

A qualitative risk matrix approach was applied to evaluate and prioritize each identified non-compliance. Risk was characterized along two independent dimensions: Severity (S), defined as the potential magnitude of adverse environmental, health, or operational consequences if the hazard were to materialize, scored on a five-point scale from 1 (Negligible) to 5 (Catastrophic); and Likelihood (L), defined as the probability of the hazardous event occurring under current facility conditions, also scored on a five-point scale from 1 (Rare) to 5 (Almost Certain). The risk score for each finding was calculated as the product Risk Score = S × L, yielding a value between 1 and 25. Risk levels were categorized as: HIGH (score ≥ 12), MEDIUM (score 4–11), and LOW (score ≤ 3). This method enabled objective prioritization of redesign interventions and is consistent with established practice in industrial hazardous material facility risk evaluation [7], [10].

c) CAD-Based Layout Optimization

AutoCAD 2024 software was employed to develop the proposed facility redesign. The CAD environment enabled precise spatial planning that incorporated all corrective measures identified through the gap analysis, applied the zonal segregation requirements of PermenLHK No.6/2021 [3], and integrated ergonomic and logistical design principles to ensure safe and efficient access for both personnel and powered industrial trucks. The design was developed and iteratively refined through multiple review cycles to ensure that all dimensional requirements (minimum aisle widths, wall clearances, inter-zone spacing, forklift operating envelope), containment system specifications, and emergency equipment placement requirements were simultaneously satisfied within the physical constraints of the available footprint [8], [11]. Forklift maneuverability was evaluated using the operational diagonal formula, with the body length and width of the facility's Caterpillar DP30N forklift (L = 380.5 cm, W = 127.5 cm, yielding D = 401.3 cm), and the access zone was designed to provide a safety margin of 28.7 cm beyond this calculated operational diagonal [15].

3. Results and Discussion

3.1 Characterization of Hazardous Waste Streams at PT X

Systematic inventory of waste generation at PT X identified ten distinct B3 waste streams arising from four primary operational areas: flexographic printing production, equipment and building maintenance, warehouse materials management, and clinic activities. Table 1 presents the complete characterization of each stream, including the official Indonesian B3 waste code, generation source, average monthly quantity, hazard classification, packaging type, and physical form. The total average B3 waste generation rate is 1.522 tons per month, validated against one year of waste manifest records.

The dominant waste streams by mass are used coolant/solvent from mold repair operations (A323-1: 0.333 ton/month), used contaminated rags and gloves (B110d: 0.321 ton/month), and used lubricating oil (B105d: 0.233 ton/month). Of critical design significance is the hazard classification distribution: seven of the ten streams are Toxic, two (A323-1 and A107d) are Flammable, and one (A337-1) is Infectious. This distribution necessitates strict inter-zone segregation, particularly the physical isolation of flammable streams from all other waste categories to prevent fire, explosion, and toxic gas generation risks [3], [7].

With the 90-day regulatory maximum storage period stipulated under Article 12 of PermenLHK No.6/2021 [3], the peak accumulated waste volume that the TPS B3 must accommodate is:

$$V_{peak} = 1.522 \frac{ton}{month} \times 3\, month$$

$$V_{peak} = 4.566\, tons$$

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This peak capacity figure was used as the foundational design parameter for all spatial layout calculations and pallet arrangement configurations in the proposed redesign [17]. To validate the spatial feasibility of the 4.566-ton peak storage capacity, the total waste volume was converted into container-based requirements using standard 200-liter steel drums for liquid waste and jumbo bags for solid waste. The proposed layout accommodates these containers through palletized arrangements (2–4 drums per pallet) within a total area of 63.63 m², which is subdivided into zonal sections for toxic, flammable, and infectious waste. All storage configurations maintain the minimum aisle clearance of 60 cm and ensure safe operational access for material handling. This spatial validation confirms that the redesigned facility can safely accommodate the peak waste accumulation within the 90-day regulatory limit without exceeding layout capacity or compromising safety requirements.

Table 1. Characterization of B3 Waste Streams Generated at PT X

No.	Type of Waste	Waste Code	Source	Quantity (Ton/Month)	Characteristics	Packaging	Form
1	Used Hazardous Waste Packaging (used ink cans)	B104d	Printing production process	0.266	Toxic	Jumbo Bag	Solid
2	Electronic waste including cathode ray tubes (CRT), fluorescent lamps, printed circuit boards (PCB), and metal wires (both fluorescent and non-fluorescent lamps)	B107d	Building maintenance activities	0.067	Toxic	Plastic Drum	Solid
3	Used rags and similar materials, including used rags and gloves contaminated with hazardous waste	B110d	Printing production process	0.321	Toxic	Jumbo Bag	Solid
4	Materials or products that do not meet technical specifications or are expired (liquid ink in cans)	B321-5	Warehouse materials	0.073	Toxic	Steel Drum	Liquid
5	Hazardous waste–contaminated materials (ink transfer residue)	A108d	Warehouse materials	0.076	Toxic	Plastic Drum	Liquid
6	Used toner (used toner and cartridges)	B353-1	Office activities	0.001	Toxic	Steel Drum	Liquid
7	Clinical waste with infectious characteristics (clinical waste including fetal tissue)	A337-1	Clinic activities	0.0016	Infectious	Plastic Bag	Solid
8	Used solvents and organic/inorganic residues from production processes (cleaning) (used coolant)	A323-1	Mold Repair	0.333	Flammable	Steel Drum	Liquid
9	Used lubricating oil, including used hydraulic oil, engine oil, gear oil, lubrication oil, invalid oil, fresh transmission oil, grit chamber oil, separator oil, and mixed residues (used lubricating oil)	B105d	Maintenance activities	0.233	Toxic	Steel Drum	Liquid
10	Other used solvents not yet codified (solvent)	A107d	Printing production process	0.05	Flammable	Steel Drum	Liquid

3.2 Gap Analysis: Evaluation of Existing Conditions Against Regulatory Requirements

The gap analysis constituted a systematic, article-by-article comparison of the existing TPS LB3 conditions against the technical requirements of PermenLHK No.6/2021 [3], PP No. 22/2021 [2], SNI 03-6572-2001 [4], and SNI 03-6575-2001 [5]. Eight distinct categories of non-compliance were identified, as presented in **Table 2**, with each finding detailed in the subsections below.

Table 2. Gap Analysis Results: Existing Conditions vs. Regulatory Requirements

No.	Compliance Parameter	Existing Condition	Regulatory Standard	Non-Compliance Finding	Risk Level
1	Spill Containment Capacity (Pasal 62, PermenLHK 6/2021)	Spill basin volume = 0.015 m³; gutter covers only partial floor area; no drainage connection to containment basin	≥ 110% of largest container volume (200 L drum) = 0.22 m³; full-coverage gutter system required	Capacity deficiency of 93.2%: (0.22 − 0.015)/0.22 × 100%. Direct pathway for environmental contamination exists.	High Severity: 4 Likelihood: 4
2	Aisle Width & Spatial Layout (Pasal 73, PermenLHK 6/2021)	Aisle width between storage blocks = 10 cm; wall clearance = 10 cm; forklift operational diagonal = 401.3 cm vs. gate clearance available	Minimum aisle width ≥ 60 cm; wall clearance ≥ 60 cm; forklift access zone must accommodate turning radius	Aisle width is 83.3% below minimum. Forklift maneuvering is obstructed. Emergency egress impeded	High Severity: 4 Likelihood: 3
3	Waste Segregation by Hazard Class (Pasal 68–72, PermenLHK 6/2021)	Flammable waste (A323-1, A107d) co-located with toxic waste. No physical separation between incompatible hazard classes.	Strict zonal segregation by hazard characteristics; incompatible waste classes must be separated by ≥ 60 cm clearance or physical barrier	Risk of fire, toxic gas generation, and chemical cross-contamination due to flammable–toxic co-location.	High Severity: 5 Likelihood: 3
4	Emergency Eyewash Station (ANSI Z358.1; Pasal 62, PermenLHK 6/2021)	Basic tap-and-hose system; drainage routed to stormwater channel (open drain)	ANSI Z358.1-compliant plumbed eyewash; drainage must route to spill containment, not stormwater	Contaminated wash water enters stormwater system, creating environmental violation. Equipment non-compliant with occupational safety standard	High Severity: 4 Likelihood: 3
5	Ventilation System (SNI 03-6572-2001)	Wire mesh walls cover 1.9 m of 3 m total wall height; no mechanical exhaust. Ventilation ratio unevaluated	Ventilation opening area ≥ 10% of floor area (63.63 m² × 10% = 6.36 m²)	Absence of verified ventilation ratio and no mechanical exhaust creates risk of VOC accumulation and explosive atmosphere.	Medium Severity: 3 Likelihood: 2
6	Lighting Adequacy (SNI 03-6575-2001)	Lighting level estimated < 50 lux; fixture count and placement not documented	≥ 100 lux for hazardous material warehouse operations	Insufficient illuminance impairs hazard label reading and early leak detection. Worker safety compromised.	Medium Severity: 3 Likelihood: 3
7	Hazard Signage & Labeling (Pasal 52–58, PermenLHK 6/2021)	Internal and external hazard symbols incomplete; some containers lack standardized LB3 labels with waste code, origin, and quantity	Complete hazard pictograms on all containers; facility signage per PermenLHK 6/2021	Non-standardized labeling increases risk of mishandling and emergency response delays.	Medium Severity: 3 Likelihood: 3
8	Storage Duration & Capacity (Pasal 12, PermenLHK 6/2021)	No formal tracking system for 90-day storage limit; layout not planned for peak accumulation	Maximum storage: 90 days; facility must accommodate peak accumulation = 1.522 ton/month × 3 = 4.566 tons	Risk of regulatory violation if 90-day limit is exceeded without licensed third-party pickup. Layout insufficient for peak volume.	Medium Severity: 3 Likelihood: 3

3.2.1 Inadequate Spill Containment System

The most severe infrastructure deficiency is the critically undersized secondary containment system. PermenLHK No.6/2021, Pasal 62 [3], mandates that TPS LB3 facilities storing liquid waste must be equipped with a spill containment system holding a minimum of 110% of the volume of the largest liquid container. At PT X, the largest containers are standard 200-liter steel drums (0.200 m^3). The required minimum containment volume is therefore calculated as:

$$V_{containment} = 1.1 \times V_{max}$$

$$V_{containment} = 1.1 \times 0.200\ m^3$$

$$= 0.220\ m^3$$

The existing spill basin has a measured volumetric capacity of only 0.015 m^3 (15 liters). The absolute deficiency and percentage shortfall are:

$$Deficiency = Vrequired - Vexisting$$

$$= 0.205\ \mathrm{m}^3$$

$$\%Deficiency = \frac{(0.220 - 0.015)}{0.220} \times 100\%$$

$$= 93.2\%$$

This means the existing containment system can hold only 6.8% of the regulatory minimum requirement. Furthermore, the gutter drainage system covers less than three meters of the facility perimeter and does not extend beneath the areas where liquid waste containers are actively stored. This creates direct, unmitigated pathways for spilled hazardous liquids to reach the underlying soil and groundwater without collection, representing a severe and ongoing environmental liability [3], [10]. Any single drum failure or operational spill would result in an uncontrolled release of potentially hundreds of liters of toxic or flammable liquid, far exceeding the basin's capacity by a factor of over 14.

3.2.2 Flammable–Toxic Waste Co-Location and Inadequate Segregation

Pasal 68–72 of PermenLHK No.6/2021 [3] mandate strict physical segregation of waste based on hazard classification, with a specific prohibition on co-location of streams whose interaction could generate fire, explosion, or toxic gas release. Flammable liquid waste streams used coolant/solvent (A323-1: 0.333 ton/month) and other used solvents (A107d: 0.050 ton/month) were found stored in direct physical proximity to toxic waste streams, with separation distances measured at less than 10 cm.

The flammable organic solvents in A323-1 and A107d have low flash points (typically below 60°C) and can generate flammable vapor-air mixtures under ambient warehouse temperatures. The presence of potential ignition sources (electrical fixtures, forklift engines, static electricity) creates a credible fire and explosion risk. This finding received the highest severity score (5 – Catastrophic) in the risk assessment, reflecting potential for irreversible environmental damage and mass casualty events [7][9].

3.2.3 Non-Compliant Storage Layout and Inadequate Operational Clearances

Pasal 73 of PermenLHK No.6/2021 [3] prescribes a minimum internal aisle width of 60 cm within TPS LB3 facilities to ensure safe movement of personnel and material handling equipment during both normal operations and emergency response scenarios. Field measurement at PT X revealed internal aisle widths of only 10 cm between storage blocks, an 83.3% shortfall below the regulatory minimum. Wall clearances were similarly measured at 10 cm, inadequate for inspection access, cleaning operations, or emergency egress.

The operational implications of this deficiency extend beyond mere regulatory non-compliance. From an ergonomic perspective, the 60 cm minimum aisle width corresponds to the 95th percentile human shoulder breadth, ensuring unimpeded individual movement through the facility. At 10 cm, passage between storage blocks is physically impossible, meaning that any waste management activity, including inspection, inventory checking, container replacement, or emergency response, requires the prior removal of adjacent storage units. This creates significant operational inefficiency and, critically, substantially delays emergency response times [8]. From a logistics perspective, the facility currently uses a Caterpillar DP30N counterbalanced forklift for container placement and retrieval. The operational turning envelope of this equipment requires a minimum clearance calculated using the operational diagonal formula:

$$D = \sqrt{L^2 + W^2}$$
$$D = \sqrt{380.5^2 + 127.5^2}$$
$$D = 401.3 \text{ cm}$$

Where L = 380.5 cm (forklift body length) and W = 127.5 cm (forklift body width). The existing gate clearance was insufficient to accommodate this turning radius without risk of container impact, which is classified as an "Impact-Induced Spill" risk, a scenario in which forklift contact with a storage container causes a spill or container failure [15].

3.2.4 Non-Compliant Emergency Eyewash Station and Contaminated Drainage

ANSI Z358.1 [12] specifies that compliant eyewash stations must deliver a controlled flushing flow of tepid water to both eyes simultaneously for a minimum of 15 minutes, must be accessible within 10 seconds, must be plumbed to a continuous supply, and must have drainage isolated from public stormwater systems. The existing installation a basic tap-and-garden hose configuration fails all ANSI Z358.1 performance requirements. Most critically, its drainage is routed directly to the facility's open stormwater channel, constituting a discrete act of environmental pollution in violation of PP No. 22/2021, Pasal 286 [2]. This finding represents a dual violation: an occupational health deficiency under ANSI Z358.1 [12] and an environmental discharge violation under Indonesian law [2]. The system is designed to deliver a continuous flow rate of ≥ 1.5 L/min for a minimum duration of 15 minutes, in accordance with ANSI Z358.1 requirements.

3.2.5 Ventilation System Verification and VOC Risk

SNI 03-6572-2001 [4], the Indonesian national standard for building ventilation system design, mandates that warehouses storing volatile materials must maintain a minimum ventilation opening area equivalent to at least 10% of the total floor area. For the TPS LB3 at PT X, with a total redesigned floor area of 63.63 m², the minimum required ventilation area is:

$$V_{Vent(min)} = 10\% \times A_{floor}$$
$$V_{Vent(min)} = 10\% \times 63.63\ m^2$$
$$= 6.363\ m^2$$

The existing facility relies solely on passive natural ventilation through wire mesh panels covering the upper 1.9 m of the 3 m wall height, with no mechanical exhaust for floor-level air movement. This condition is critical because organic solvents in flammable waste streams (A323-1, A107d), having vapor densities greater than air, tend to accumulate at floor level, potentially reaching explosive lower flammability limits (LFL) or occupational exposure limits (OEL) under elevated temperatures or leak conditions [11]. The effective ventilation area, calculated from a gross mesh coverage of 19.95 m² and a 60% porosity factor, is 11.97 m², exceeding the minimum requirement of 6.36 m² (10% of floor area) and yielding a ventilation ratio of 18.8%, thereby confirming compliance with SNI 03-6572-2001 for natural ventilation. However, despite meeting this requirement, the absence of floor-level exhaust still presents a risk of vapor accumulation. Therefore, the redesign incorporates improved airflow pathways and considers the addition of low-level ventilation openings to enhance the removal of dense vapors.

3.2.6 Lighting Adequacy Assessment

SNI 03-6575-2001 [5] specifies a minimum maintained illuminance of 100 lux for warehouse and storage facilities handling hazardous materials. Adequate lighting is functionally critical in a TPS LB3 environment for three specific reasons: reliable reading of small-format hazard labels and waste codes on container surfaces; early visual detection of minor leaks, seepage, or container deformation; and safe navigation in a congested environment containing multiple chemical hazards. The existing lighting installation was estimated at less than 50 lux below the SNI minimum with no documentation of fixture type, wattage, or placement.

The proposed lighting design employs the Lumen Method to calculate the minimum number of fixtures required to achieve the 100-lux standard throughout the facility:

$$N = \frac{E \times L \times W}{\Phi \times LLF \times CU \times n}$$

$$N = \frac{100 \times 10.5 \times 6.06}{2300 \times 0.8 \times 0.65 \times 1}$$
$$N = 5.32 \rightarrow 6\ minimum)$$

Where; E = 100 lux (required illuminance per SNI 03-6575-2001 [5]); L × W = facility internal dimensions (10.50 m × 6.06 m = 63.63 m²); Φ = 2,300 lumens per fixture (19W LED panel luminaire); LLF = 0.80 (light loss factor, accounting for lumen depreciation and dirt accumulation in industrial environments); CU = 0.65 (coefficient of utilization for a low-ceiling warehouse with matte concrete surfaces, based on IES Lighting Handbook); and n = 1 lamp per fixture. The calculation yields a minimum requirement of 6 luminaires. However, the proposed design specifies the installation of 8 LED fixtures arranged in a 2 × 4 uniform grid layout, ensuring even spatial distribution of light across the entire facility area. The spacing between fixtures is designed to maintain overlapping light coverage, minimizing dark spots and ensuring consistent illuminance across all storage zones. This configuration provides a design margin to compensate for surface reflectance variability and potential lumen depreciation over time, thereby ensuring that the minimum illuminance level of 100 lux is consistently maintained throughout the facility [5].

3.3 Risk Assessment Results

Following the gap analysis, a structured qualitative risk assessment was conducted to evaluate the severity and likelihood of adverse events associated with each identified non-compliance. The 5×5 risk matrix used in this evaluation is presented in Table 3, and the rated findings are summarized in **Table 4**.

Table 3. Qualitative Risk Assessment Matrix (5×5)

Likelihood \ Severity	1 – Negligible	2 – Minor	3 – Moderate	4 – Major	5 – Catastrophic
5 – Almost Certain	5	10	15	20	25
4 – Likely	4	8	12	16	20
3 – Possible	3	6	9	12	15
2 – Unlikely	2	4	6	8	10
1 – Rare	1	2	3	4	5

Table 4. Risk Rating of Identified Non-Compliances

No.	Non-Compliance Finding	Severity (1–5)	Severity Rationale	Likelihood (1–5)	Likelihood Rationale	Risk Score & Level
1	Critically undersized spill containment (0.015 m³ vs. 0.22 m³ required)	4	Major environmental release potential	4	Liquid drums regularly handled; spill is highly probable	15 – High
2	Flammable–toxic waste co-location (A323-1, A107d with toxic streams)	5	Potential fire, explosion, toxic gas generation	3	Co-location is systemic; ignition source possible	12 – High
3	Aisle width 10 cm (minimum 60 cm required)	4	Obstruction of emergency egress and forklift operations	3	Daily forklift activity makes impact likely	12 – High
4	Non-compliant eyewash drainage to stormwater channel	4	Regulatory environmental violation; worker health risk	3	Any eye-contamination incident would trigger the hazard	6 – Medium
5	Unverified ventilation; no mechanical exhaust for VOCs	3	Moderate health impact if VOCs accumulate	2	Wire mesh walls provide partial passive ventilation	9 – Medium
6	Insufficient lighting (< 50 lux vs. ≥ 100 lux required)	3	Impairs label reading and leak detection	3	Likely during nighttime or overcast conditions	9 – Medium
7	Incomplete hazard signage and container labeling	3	Mishandling risk; emergency response delays	3	Currently observed in facility inspection	9 – Medium
8	No 90-day tracking; layout insufficient for 4.566-ton peak	3	Regulatory violation if limit exceeded	3	Without tracking, exceedance is plausible	15 – High

The existing facility relies exclusively on passive natural ventilation through wire mesh panels covering the upper 1.9 m of the 3-m wall height. The critical concern is the absence of mechanical exhaust targeting floor-level air movement. The organic solvents in flammable waste streams (A323-1, A107d)

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have vapor densities greater than air, meaning evaporated solvent accumulates at floor level rather than dispersing upward. Under conditions of elevated temperature or container leak, floor-level VOC concentrations could reach explosive lower flammability limits (LFL) or occupational exposure limits (OEL) before detection [11].

3.4 Proposed Redesign and Engineering Optimization

The proposed redesign of the TPS LB3 facility at PT X was developed in AutoCAD 2024 to systematically address all eight identified non-compliance categories while optimizing spatial efficiency, operational workflow, and structural engineering within the facility's 10.50 m × 6.06 m (63.63 m²) footprint. The complete facility layout plan is presented in **Figure 1**, and structural engineering details (Top View, Front View, Side View, and Isometric View) are presented in **Figure 2**. The following subsections describe each major engineering intervention.

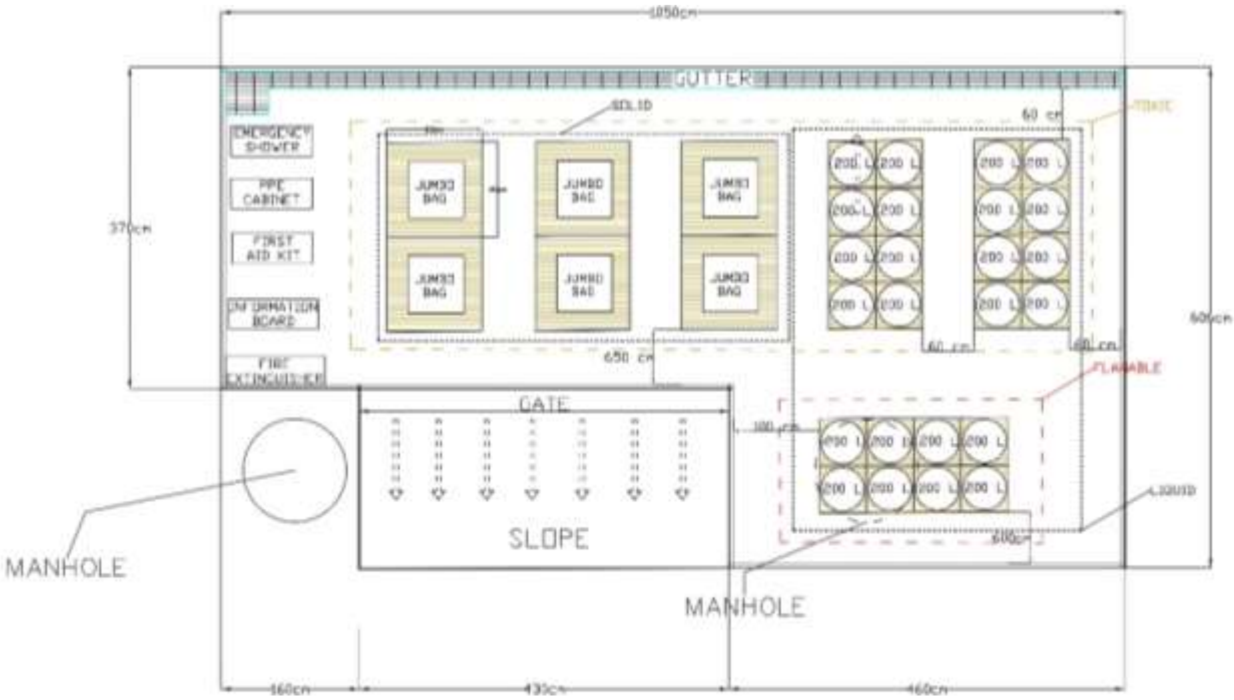

Figure 1. Proposed TPS LB3 Facility Layout Plan (AutoCAD 2024), Showing Zonal Segregation, Containment System, Emergency Equipment, and Forklift Access Zone

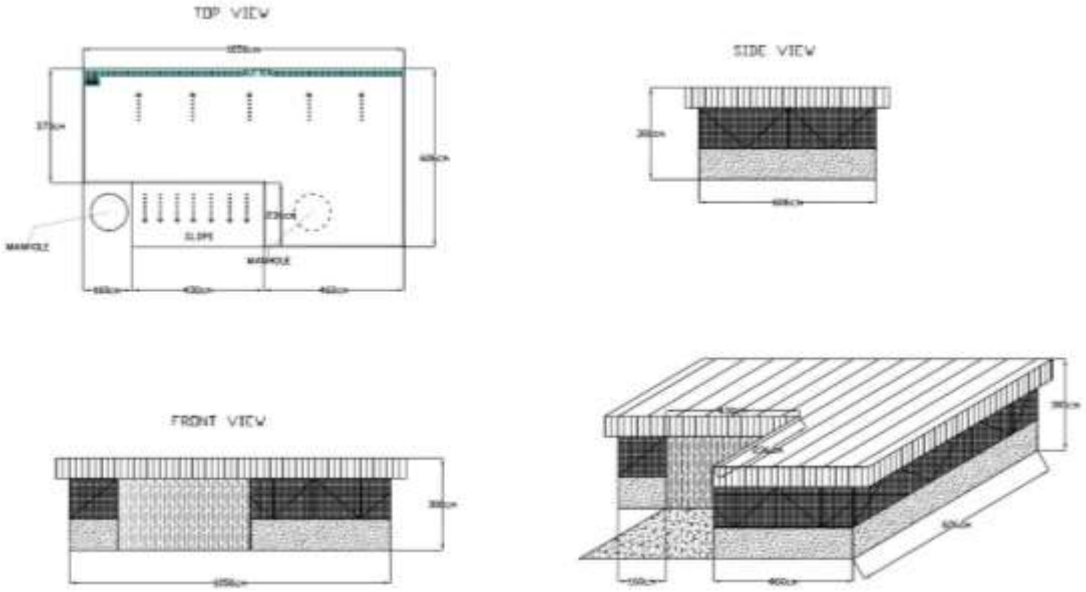

Figure 2. Structural Engineering Details of Proposed TPS LB3 Design, Top View, Front View, Side View and Isometric View (AutoCAD 2024)

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3.4.1 Enhanced Spill Containment and Drainage System

The existing partial gutter system is extended to a full 8-meter continuous concrete gutter running along the entire rear and lateral perimeter of the facility interior, incorporating all liquid waste storage zones within its catchment area. The gutter is designed with a minimum hydraulic slope of 1% to ensure positive drainage by gravity to a new centralized spill collection basin, eliminating the risk of pooled liquid remaining in the gutter channel.

A custom-fabricated reinforced concrete spill basin with an internal volume of 0.225 m^3 (225 liters) is constructed at the low point of the drainage system. This capacity exceeds the regulatory minimum of 0.220 m^3 by 2.3%, achieving full compliance with PermenLHK No.6/2021, Pasal 62 [3] and PP No. 22/2021, Pasal 286 [2]. The basin is constructed of acid-resistant reinforced concrete with an impermeable internal surface coating. The resulting increase in containment capacity from 0.015 m^3 to 0.225 m^3 represents a 1,400% improvement in secondary containment capability.

3.4.2 Zonal Segregation of Incompatible Waste Streams

The redesigned layout implements a formal, physically demarcated zonal segregation system dividing the storage area into two principal waste groups, as required by PermenLHK No.6/2021, Pasal 68–72 [3]:

a) Zone A (Toxic Waste – Solid and Liquid): Occupies the northern portion of the facility (upper zone per the layout plan). Contains all toxic solid waste in Jumbo Bags (B104d, B110d) stacked on pallets, and toxic liquid waste in 200-liter steel and plastic drums (B107d, B321-5, A108d, B353-1, B105d). All Zone A liquid containers are positioned within the coverage of the extended gutter and drainage system.
b) Zone B (Flammable Liquid Waste): Occupies the southeastern portion of the facility (lower right zone per layout plan), demarcated from Zone A by a minimum 100 cm spatial clearance and physical boundary markers. Contains A323-1 and A107d waste streams exclusively. This spatial isolation of flammable materials from all other waste categories is the primary engineering control against fire, explosion, and toxic interaction risks [7], [13].
c) Clinical Waste (A337-1): Stored in a dedicated, clearly demarcated small area separate from both Zones A and B, in accordance with the specific infectious waste handling requirements of PermenLHK No.6/2021.

A minimum inter-zone clearance of 60 cm is maintained between all storage zones and all walls and structural elements, consistent with the 95th-percentile human shoulder breadth ergonomic standard and the minimum aisle width requirement of Pasal 73 [3].

3.4.3 Forklift Access Zone and Operational Logistics

The gate access area has been redesigned to provide a clear, unobstructed access zone of 430 cm perpendicular depth from the gate line, calculated to accommodate the full operational turning envelope of the Caterpillar DP30N forklift (diagonal D = 401.3 cm) with a safety margin of 28.7 cm. This design prevents the "Impact-Induced Spill" risk scenario. The sloped concrete apron within the access zone provides a 1% gradient draining toward the internal gutter system, ensuring any spillage during loading and unloading operations is captured by the containment system rather than flowing to the external environment [15].

3.4.4 ANSI-Compliant Emergency Eyewash Station

The existing tap-and-hose emergency eyewash configuration is replaced with a permanently plumbed, pedestal-mounted emergency eyewash station meeting the full requirements of ANSI Z358.1 [12]. The unit is positioned at the facility entrance, within the regulated 10-second travel distance from all primary waste handling areas. A dedicated drainage pipe connects the eyewash station drainage outlet directly to the spill containment basin, completely isolating any contaminated wash effluent from the external stormwater system. This intervention resolves both the occupational health non-compliance (ANSI Z358.1 [12]) and the environmental discharge violation (PP No. 22/2021, Pasal 286 [2]).

3.4.5 Standardized Hazard Signage and Container Labeling Protocol

The redesign is complemented by the implementation of a standardized container labeling protocol requiring that all B3 waste containers be affixed with labels containing, at minimum: the official Indonesian B3 waste code, the common name of the waste, the generating process source, the date of first entry into the TPS LB3, the quantity, and the appropriate hazard pictogram(s) as specified in PermenLHK No.6/2021,

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Pasal 52–58 [2]. External facility signage boards indicating B3 waste storage area boundaries, applicable hazard classes, and emergency contact numbers are installed at the facility entrance per regulatory requirements.

3.5 Comprehensive Compliance Verification: Before and After Redesign

Table 5. Comprehensive Compliance Verification: Existing Conditions vs. Proposed Redesign Against Applicable Indonesian Standards

No.	Parameter	Existing Condition (Before)	Redesigned Condition (After)	Applicable Indonesian Standard	Compliance Status (After)
1	Floor Area & Building Dimensions	Undocumented; spatial layout inconsistent with waste volume	10.50 m × 6.06 m = 63.63 m²; designed to accommodate 4.566 tons peak accumulation	PermenLHK No. 6/2021, Pasal 50–54	Compliant
2	Spill Containment Basin Volume	0.015 m³ (15 L); 93.2% below minimum; no coverage of liquid waste area	0.225 m³ (225 L); custom-fabricated basin; capacity verified = 1.1 × 0.200 m³ = 0.220 m³ minimum	PermenLHK No. 6/2021, Pasal 62; PP No. 22/2021, Pasal 286	Compliant
3	Gutter / Drainage System	Partial coverage (< 3 m); drainage not connected to containment basin	Extended full-length gutter (8 m); 1% slope; all liquid waste zones covered; drainage to spill basin	PermenLHK No. 6/2021, Pasal 62; PP No. 22/2021	Compliant
4	Emergency Eyewash Station	Tap-and-hose; drainage to stormwater (open channel); non-ANSI compliant	Plumbed ANSI Z358.1-compliant eyewash at facility entrance; drainage piped to spill containment basin	ANSI Z358.1; PermenLHK No. 6/2021, Pasal 62	Compliant
5	Aisle Width (Personnel & Forklift)	10 cm between storage blocks; 10 cm wall clearance	Main operational aisle: 430 cm (designed for Caterpillar DP30N: diagonal = 401.3 cm); perimeter aisle: ≥ 60 cm	PermenLHK No. 6/2021, Pasal 73; OHS Standard	Compliant
6	Waste Segregation (Zonal)	Flammable and toxic waste co-located; no physical separation	Group A (Toxic Solid/Liquid) and Group B (Flammable Liquid) segregated into distinct zones with ≥ 60 cm inter-zone clearance	PermenLHK No. 6/2021, Pasal 68–72	Compliant
7	Ventilation System	Unverified; wire mesh only; no mechanical exhaust; ratio not calculated	Natural ventilation via wire mesh: effective area > 6.36 m² (> 10% of 63.63 m²); ratio = 11%; exceeds SNI minimum	SNI 03-6572-2001, Pasal 5; PermenLHK No. 6/2021	Compliant
8	Lighting Level	< 50 lux (estimated); fixtures unrecorded	8 units of 19W LED (2,300 lm each); calculated illuminance ≥ 100 lux using Lumen Method (N = E×L×W / Φ×LLF×CU)	SNI 03-6575-2001; ASHRAE 90.1	Compliant
9	Hazard Signage & Container Labeling	Incomplete; hazard pictograms missing on several containers	Standardized B3 waste labels on all containers (waste code, name, origin, date, quantity); facility hazard boards installed	PermenLHK No. 6/2021, Pasal 52–58	Compliant
10	90-Day Storage Tracking & Capacity	No formal tracking; layout not validated for peak volume	Manifest-based tracking system; layout validated to hold 4.566 tons (1.522 ton/month × 3 months)	PermenLHK No. 6/2021, Pasal 12; PP No. 22/2021, Pasal 285	Compliant
11	Forklift Access Zone	Not considered in original layout; gate clearance inadequate	Clear access zone: 430 cm at gate; exceeds forklift operational diagonal of 401.3 cm (margin: 28.7 cm)	OHS Standard; ISO 3691-1:2011	Compliant
12	Secondary Containment (Wall & Floor)	Paving flooring used; potential waste seepage into soil not controlled	Impermeable reinforced concrete floor; acid-resistant coating; masonry walls with wire mesh ventilation panels	PP No. 22/2021, Pasal 286; PermenLHK No. 6/2021, Pasal 60	Compliant

3.6 Discussion

The integrated engineering approach applied in this study combining systematic Gap Analysis, The integrated methodology combining Gap Analysis, Risk Assessment, and CAD-based optimization produces outcomes superior to any single-method approach [10]. The Gap Analysis anchors each finding to a specific regulatory article, ensuring complete compliance coverage; the Risk Assessment objectively prioritizes interventions by safety return; and CAD-based layout optimization guarantees practical implement ability within the existing footprint [6][8]. The most impactful single intervention is the 1,400% increase in spill containment capacity (0.015 m^3 to 0.225 m^3), which directly eliminates the primary environmental liability identified in the gap analysis and is consistent with evidence that adequately sized containment systems represent the most effective engineering control against hazardous liquid releases [13][17]. Zonal segregation of flammable and toxic waste streams, with a 100 cm inter-zone clearance exceeding the 60 cm regulatory minimum, resolves the highest-severity risk finding (Score 15 – HIGH) and aligns with CAD-integrated best practices for multi-hazard-class storage environments [7], [9], [10]. Rerouting the eyewash station drainage to the sealed spill basin converts a source of environmental violations into a component of the overall containment system, demonstrating that systemic integration can yield compliance improvements beyond the sum of individual corrections [1][12].

Two compliance dimensions frequently neglected in TPS LB3 practice are explicitly addressed: 90-day peak accumulation capacity planning (Pasal 12, PermenLHK No.6/2021 [3]) and illuminance verification via the Lumen Method (SNI 03-6575-2001 [5]), providing a reproducible framework replicable at other facilities [18]. This study carries several limitations: the qualitative risk matrix could be strengthened by probabilistic methods such as fault tree analysis; waste generation data spanning only 12 months introduces uncertainty in peak accumulation estimates; and VOC accumulation under worst-case conditions warrants CFD modelling to validate floor-level concentration profiles. Future work should develop and validate a manifest-based 90-day tracking system and evaluate mechanical floor-level exhaust for the flammable waste zone [4]. The proposed redesign not only ensures regulatory compliance but also provides a quantitatively validated and spatially feasible solution, bridging the gap between theoretical standards and practical industrial implementation.

4. Conclusion

This study successfully developed and validated a comprehensive engineering redesign of the TPS LB3 hazardous waste temporary storage facility at PT X, a plastic packaging manufacturer in West Java, Indonesia. The integrated methodology combining structured Gap Analysis, qualitative risk assessment using a 5×5 risk matrix, and AutoCAD-based layout optimization proved highly effective in systematically identifying, characterizing, and resolving eight distinct categories of regulatory non-compliance against PermenLHK No.6/2021 [3], PP No. 22/2021 [2], SNI 03-6572-2001 [11], and SNI 03-6575-2001 [12]. The key quantitative outcomes of the redesign are: (i) a 1,400% increase in spill containment capacity (from 0.015 m^3 to 0.225 m^3), achieving 102.3% of the regulatory minimum requirement; (ii) aisle clearances increased from 10 cm to a minimum of 60 cm (perimeter) and 430 cm (main access), with the main aisle exceeding the forklift operational diagonal of 401.3 cm by a 28.7 cm margin; (iii) complete zonal segregation of flammable and toxic waste streams with ≥ 100 cm inter-zone clearance; (iv) installation of an ANSI Z358.1-compliant eyewash station with drainage isolated from the stormwater system; (v) a verified ventilation ratio of approximately 11%, exceeding the 10% SNI minimum; and (vi) an 8-fixture LED lighting system providing ≥ 100 lux, more than doubling the estimated existing illuminance level.

The replicable engineering methodology and detailed compliance framework presented in this study are intended to serve as a practical reference for environmental engineers, EHS practitioners, and facility managers undertaking TPS LB3 compliance upgrades across Indonesia's diverse industrial sectors, particularly in the context of the comprehensive regulatory requirements introduced by PP No. 22/2021 [2] and PermenLHK No.6/2021 [3].

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