

# ASSESSING OCCUPATIONAL HEALTH AND SAFETY STANDARDS IN WELDING FACILITIES: A DELPHI-AHP CASE STUDY AT A VOCATIONAL HIGHER EDUCATION INSTITUTION IN JAKARTA

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## Abstract

*Evaluating safety in higher vocational education demands context-specific tools, rather than standard industrial checklists. Academic welding workshops pose significant occupational risks. Students are exposed to hazards such as heavy metal fumes, extreme temperatures, and radiation. Often, institutions rely on corporate audit templates, which may not align with the high-turnover, low-experience environment of a polytechnic laboratory. To address this, this study constructed an Occupational Health and Safety (OHS) index specifically for vocational higher education. Integrating a two-stage Delphi panel with the Analytical Hierarchy Process (AHP), academics and safety auditors distilled broad regulations into five core pillars. AHP calculations identified Local Exhaust Ventilation (C1) as the highest priority, with a weight of 0.416. The expert judgments were highly consistent (CR = 0.024). Applying this index in a field audit at a Jakarta polytechnic, the facility earned an overall compliance score of 61.03 out of 100. While the workshop scored 85 for enforcing personal protective equipment (PPE), it scored 50 for source ventilation. These results highlight the limitations of partial compliance. Relying on PPE while lacking adequate fume extraction may provide insufficient protection. This framework offers a data-backed guide for institutions to prioritize localized exhaust networks to better protect students' respiratory health.*

## Keywords:

*Welding safety; Vocational education; Delphi method; Analytical Hierarchy Process; Risk assessment..*

## Abstrak

Evaluasi keselamatan kerja pada perguruan tinggi vokasi membutuhkan instrumen spesifik secara konteks, alih-alih *checklist* industri standar. Bengkel pengelasan akademik memiliki risiko keselamatan kerja yang signifikan. Mahasiswa sering terpapar berbagai bahaya seperti emisi asap logam berat, suhu ekstrem, dan radiasi. Seringkali, institusi pengelola bergantung pada templat audit perusahaan komersial, yang mungkin tidak selaras dengan lingkungan laboratorium politeknik yang memiliki tingkat pergantian pengguna yang tinggi dengan tingkat pengalaman yang rendah. Untuk mengatasi hal ini, penelitian ini menyusun indeks Keselamatan dan Kesehatan Kerja (K3) khusus untuk pendidikan tinggi vokasi. Dengan mengintegrasikan panel Delphi dua tahap dan *Analytical Hierarchy Process* (AHP), para akademisi dan auditor keselamatan menyaring berbagai regulasi menjadi lima pilar utama. Perhitungan matriks AHP mengidentifikasi Sistem Ventilasi Lokal (C1) sebagai prioritas tertinggi dengan bobot 0,416. Penilaian dari para pakar tersebut terbukti sangat konsisten (CR = 0,024). Penerapan indeks ini dalam audit lapangan di sebuah politeknik di Jakarta menunjukkan bahwa fasilitas tersebut memperoleh skor kepatuhan keseluruhan sebesar 61,03 dari skala 100. Meskipun bengkel praktik tersebut memperoleh skor 85 untuk penegakan Alat Pelindung Diri (APD), skor untuk ventilasi penangkap asap di sumbernya hanya mencapai 50. Hasil penelitian ini menyoroti keterbatasan

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dari kepatuhan keselamatan yang bersifat parsial. Bergantung pada penyediaan APD sembari kekurangan infrastruktur ekstraksi asap yang memadai dapat memberikan perlindungan yang tidak mencukupi. Kerangka kerja ini menawarkan panduan berbasis data bagi institusi untuk memprioritaskan pengadaan jaringan *exhaust* lokal guna melindungi kesehatan pernapasan mahasiswa dengan lebih efektif.

#### Kata Kunci:

Keselamatan pengelasan, Pendidikan vokasi tinggi, Metode Delphi, *Analytical Hierarchy Process*, Penilaian fasilitas.

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## 1. INTRODUCTION

Higher vocational education institutions play an essential role in fulfilling the demand for highly skilled technical labor across global manufacturing, manufacturing automation, and structural engineering sectors. The foundational pedagogical framework of these institutions prioritizes intensive hands-on practical engagement over theoretical instruction, ensuring that student cohorts log substantial operational hours within specialized engineering workshops and laboratories (Flynn & Susi, 2012). Mechanical engineering curricula lean heavily on welding workstations encompassing SMAW, GMAW, FCAW, and GTAW modalities. These specific bays are heavily utilized operational zones on campus. The metallurgical physics that make welding an industrial competency also introduce occupational hazards into the academic laboratory, (Anwar et al., 2024; Pirvu et al., 2024).

The welding process involves a highly concentrated energy release. Novice operators fuse metallic substrates in an environment that presents risks of high-voltage shocks and hot spatter. Additionally, the process emits ultraviolet and infrared radiation, posing risks to eye health. Furthermore, the thermal process generates aerosolized particulate matter and toxic fumes, including manganese and hexavalent chromium (Anwar et al., 2024; Jagodang Harahap, 2022). Yet, it is the insidious, microscopic threats that execute the most profound physiological damage. Arc ignition instantaneously unleashes an aggressive spectrum of ultraviolet and infrared radiation, presenting a severe risk of acute photokeratitis and threatening permanent retinal degradation (Fahzan Bin Salleh et al., 2020). Concurrently, the extreme thermal annihilation of electrodes and base metals vaporizes a dense, suffocating cloud of toxic aerosols. These welding fumes carry heavy payloads of aggressive heavy metals predominantly neurotoxic manganese and carcinogenic hexavalent chromium (Fahzan Bin Salleh et al., 2020). Exposing inexperienced students to these airborne particulates in poorly ventilated spaces increases the risk of respiratory and neurological health issues, (Andika et al., n.d.; Nurul Amalia et al., n.d.). It is important to note that the hazard descriptions in this study are framed based on established clinical and toxicological literature; no empirical measurements of air quality, fume exposure, or direct physiological health data were recorded during this assessment.



Figure 1. Condition Of Welding Workstation

Despite these lethal biological realities, institutional safety governance remains shockingly lethargic. Polytechnic administrators exhibit a deeply problematic reliance on generic OHS audit checklists imported directly from an automotive assembly plants (Efendi et al., 2020). These corporate auditing protocols are structurally incapable of evaluating a campus laboratory. These corporate audit checklists are structurally not suitable to be used as evaluation tools for a campus laboratory. Industrial shop floor relies on a stagnant demographic of highly trained workers doing repetitive tasks within controlled performance. Conversely, a higher vocational institution such as Jakarta State Polytechnic is defined by relentless, high velocity operational error. (Arief Alfianto et al., 2023). Green student cohorts cycle rapidly through tight welding cabins week after week. Lacking fundamental muscle memory, struggling with basic situational awareness, and entirely devoid of long-term hazard context, this unique demographic requires a radically customized approach to risk mitigation (Suhardi & Zetli, 2021).

Relying on mismatched evaluation rubrics can lead to misdirected financial decisions. Campuses may allocate budgets toward administrative controls or disposable PPE, while critical engineering infrastructure is overlooked or the installation of colorful administrative safety banners. Meanwhile, fundamental, high-capital engineering infrastructure is blatantly ignored (Saaty, 1999). The absence of localized source-capture ventilation networks remains a chronic, fatal blind spot. Addressing this requires providing policymakers with robust decision-making models to identify necessary infrastructural upgrades (Vaidya & Kumar, 2006).

Addressing this systemic administrative failure, this research engineers a bespoke safety evaluation framework tailored explicitly for the polytechnic ecosystem. We initiated this overhaul utilizing the Delphi technique, a robust methodology renowned for synthesizing disparate opinions from independent veterans into a unified, context-specific consensus (Silitonga, 2019). Once the expert panel defined the core safety parameters, we subjected those exact criteria to the unforgiving mathematics of Saaty's Analytical Hierarchy Process (AHP) (Tomy Syahputra ButarButar & Susanto Hariyadi, 2023). Stripping away subjective academic bias, AHP forces a systematic pairwise comparison of every variable, ultimately translating expert judgments into unyielding, quantified priority weights while executing strict internal consistency checks, (Khodadadi-Karimvand & Taherifar, 2022). Across numerous industrial sectors, this hybrid MCDM framework has repeatedly proven its analytical supremacy.

Ultimately, this study dismantles the dangerous reliance on generic industrial guidelines within academic settings. By fusing a multi-stage Delphi panel with AHP matrix processing driven by leading safety practitioners and engineering academics, we ruthlessly reconstructed the core pillars of welding safety from the ground up. Armed with these mathematically verified weights, the research team executed a comprehensive field audit across multiple bays of a prominent state polytechnic in Jakarta. The resulting gap analysis mercilessly exposes critical infrastructural vulnerabilities, providing institutional leaders with a definitive, data-backed roadmap for strategic OHS capital reallocation.

## 2. LITERATURE REVIEW

### 2.1. Material Toxicity and Occupational Hazards in Welding Metallurgy

Delving into the chemistry of high-temperature arc welding uncovers a staggering array of toxicological threats. What an operator ultimately inhales is strictly governed by the complex interplay between the consumable wire, the electrode flux, the shielding gases, and the specific base metal being manipulated. Consider the mechanics of Shielded Metal Arc Welding (SMAW). As the flux coating violently burns away, it generates a massive volume of aerosolized particulate matter. Because the vast majority of these particles possess aerodynamic diameters well below 1.0 micrometer, they effortlessly bypass the body's upper respiratory defenses, penetrating deep into the alveolar regions of the lungs.

Manipulating standard carbon steel wire introduces manganese directly into the operator's breathing zone, representing a profound neurotoxic hazard. Extensive clinical literature demonstrates that chronic manganese inhalation facilitates heavy metal accumulation within the brain's basal ganglia, ultimately triggering irreversible motor dysfunctions. Transitioning to stainless steel substrates swaps one poison for another; the extreme thermal energy oxidizes chromium into hexavalent chromium (Cr(VI)) vapor. Recognized globally as a highly aggressive Group 1 carcinogen, Cr(VI) is notoriously linked to pulmonary carcinoma and the severe ulceration of the nasal septum. Given these terrifying biological consequences, stringent regulatory bodies like OSHA explicitly mandate absolute containment protocols. Standard 29 CFR 1910.252 makes it unequivocally clear that relying on ambient, general dilution ventilation is a fundamentally flawed strategy for protecting an operator's breathing zone (15-CFR-2005-Title29-Vol5-Sec1910-252, n.d.).

Contemporary research reinforces this stance, proving that merely circulating air with standard wall fans only serves to disperse the toxic plume across the entire laboratory, indiscriminately exposing passing students and instructors to identical respiratory hazards.

## 2.2. Socio-Technical Dynamics and OHS Structural Vulnerabilities in Higher Vocational Environments

Policing occupational safety within the boundaries of a higher vocational institution presents socio-technical challenges that simply do not exist on a commercial shop floor. In the realm of heavy industry, workers are subjected to grueling, structured safety orientations prior to ever touching a machine. They hold professional certifications, operate under strict union guidelines, and face immediate legal or financial termination for violating OHS protocols (Cena et al., n.d.)

Conversely, the primary demographic utilizing polytechnic workshops consists of novice trainees briefly dropping in to fulfill weekly academic credits. Possessing significantly lower baseline situational risk perception, these student cohorts consistently display higher error rates driven by undeveloped muscle memory and a structural tendency to misinterpret or blatantly ignore safety briefings. The sheer operational density of these academic spaces severely exacerbates the danger. Cramping up to thirty inexperienced students into a single, enclosed laboratory each simultaneously striking independent arcs generates an incredibly intense, localized concentration of physical hazards and toxic emissions.

Compounding this demographic vulnerability is the glacial pace of state-funded bureaucracy. When a polytechnic requires a substantial capital upgrade such as a modern fume extraction network administrators are frequently paralyzed by rigid public procurement cycles, resulting in multi-year delays. This unique combination of high-density novice operators and slow-moving budgets highlights exactly why localized OHS evaluation tools are so critical. If academic institutions continue leaning on generic administrative checklists, they risk perpetuating a superficial culture of safety compliance that looks excellent on paper but leaves students breathing poison (Sayuti et al., 2024).

## 2.3. Fusing Delphi Consensus with AHP for Custom OHS Metrics Derivation

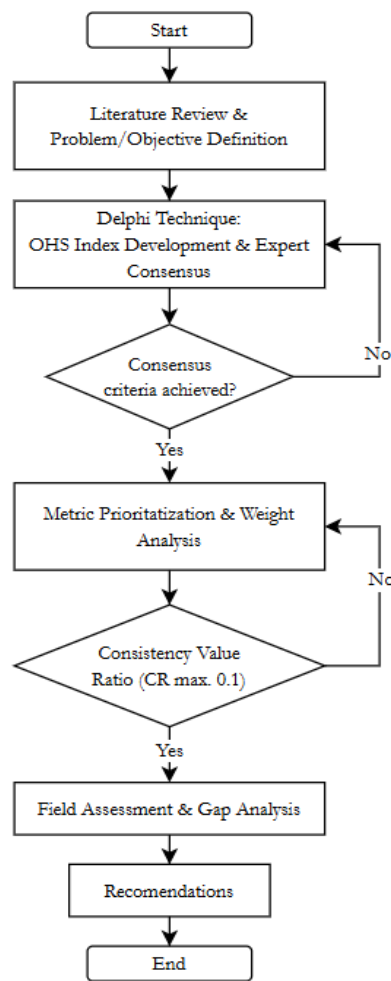
Constructing an evaluation metric that is simultaneously practical for a vocational setting and mathematically unassailable requires the strategic integration of qualitative and quantitative Multi-Criteria Decision-Making (MCDM) methodologies (Vaidya & Kumar, 2006). Serving as the optimal starting point, the Delphi technique allows researchers to filter massive, overly broad regulatory guidelines through the highly contextualized lens of local expert knowledge. By leveraging multi-round, anonymous questionnaires, Delphi effectively neutralizes dominant personalities, facilitating a pure, uninhibited convergence of opinion on which safety parameters actually dictate survival in a campus lab.

However, Delphi possesses a structural limitation. While it successfully identifies what is important, it completely fails to quantify exactly how much more important one variable is over another. This is precisely where the Analytical Hierarchy Process (AHP) proves invaluable (Silitonga, 2019). AHP mathematically weaponizes the Delphi consensus by forcing experts to subject every validated criterion to rigorous, head-to-head pairwise comparisons. Extracting the principal eigenvector from this comparison matrix allows AHP to generate exact percentage weights for each safety element. Crucially, its built-in consistency evaluation acts as a mathematical lie detector, immediately flagging flawed or contradictory human judgments before they impact the final index.

## 3. RESEARCH METHODOLOGY

### 3.1 Mixed-Methods Systemic Framework

Driving this investigation is a highly structured, descriptive-evaluative design anchored by a mixed-methods framework. We systematically compartmentalized the research into three distinct operational phases. Initially, we deployed a two-stage Delphi expert panel to qualitatively synthesize and refine the preliminary safety parameters. Subsequently, we transitioned to a purely quantitative approach, utilizing Saaty's Analytical Hierarchy Process to extract matrix weights and validate internal consistency. Finally, we grounded our theoretical model in reality, executing a brutal factual field audit and gap analysis across three separate bays of the Mechanical Engineering welding laboratory at Jakarta State Polytechnic. The holistic architecture of this methodology is visually codified in Fig. 2



**Figure 2.** Research Metodology Flow Chart.

### 3.2 Delphi Panel Selection and Consensus Thresholds

Recognizing that the integrity of our data relied entirely on the caliber of our experts, we utilized a ruthless purposive sampling strategy. Securing a seat on the five-member Delphi panel required a minimum of ten years of verifiable, direct engagement in OHS engineering, heavy industrial welding supervision, or higher vocational pedagogy. The finalized roster was formidable. It comprised two senior metallurgy professors from state polytechnics, a veteran chief workshop instructor holding international welding certifications, and two elite OHS lead auditors extracted directly from the heavy manufacturing sector. The demographic breakdown of this panel is detailed in Table 1.

**Table 1.** Delphi Expert Panel Demographics

| ID  | Title & Affiliation                             | Domain Expertise                 |
|-----|-------------------------------------------------|----------------------------------|
| E01 | Senior lecturer, State Polytechnic              | Welding Metallurgy, Academic OHS |
| E02 | Chief Workshop Instructor, Voc. Training Center | Practical Welding (SMAW/GMAW)    |
| E03 | Lead OHS Auditor, Heavy Manufacturing           | ISO 45001, Industrial Safety     |
| E04 | Senior OHS Consultant, National Safety Council  | Risk Assessment, Ergonomics      |
| E05 | Associate Professor, State Polytechnic          | MCDM, Systems Engineering        |

Initiating Round 1, we bombarded the panel with twenty dense preliminary safety parameters extracted straight from OSHA 29 CFR 1910.252 via an open-ended questionnaire. The experts ruthlessly graded each

parameter on a 5-point Likert scale, assessing its actual containment value for a chaotic student laboratory. Any parameter failing to secure a minimum 70% consensus was immediately purged. Round 2 resubmitted the surviving variables, forcing the experts to hammer out a final, unbreakable consensus. What remained were five definitive, non-negotiable core pillars of welding safety.

### 3.3. Mathematical Formulations of the AHP Weights Matrix

With the result from five essential criteria (C1–C5), we ask the expert panel to evaluate all criteria mathematically. Each expert executed an independent pairwise comparison matrix, scoring the variables against each other using the classic Saaty linear scale (1–9). To fuse these disparate matrices without distorting the mathematical properties of their reciprocal judgments, we aggregated the data utilizing the geometric mean method. Let this definitive consolidated matrix be denoted as  $A = [a_{ij}]$ , where  $a_{ij}$  represents the absolute dominance of criterion  $i$  over criterion  $j$ . Prior to aggregation, each individual expert's pairwise comparison matrix was independently evaluated to ensure the Consistency Ratio (CR) was strictly below the 0.10 threshold, thereby guaranteeing the mathematical validity of their judgments before consolidation.

Extracting the criteria weights (the principal eigenvector,  $W$ ) required dividing each element by the sum of its respective column, subsequently calculating the row averages. Crucially, to guarantee our experts hadn't generated logically contradictory judgments, we computed the maximum eigenvalue ( $\lambda_{max}$ ) and derived the Consistency Index (CI) utilizing Equation (1):

$$CI = (\lambda_{max} - n) / (n - 1) \quad (1)$$

Where  $n$  signifies the matrix order ( $n = 5$ ). The final mathematical hurdle involved computing the Consistency Ratio (CR) via Equation (2), dividing the CI by the established Random Index (RI) of 1.12 for a 5x5 matrix:

$$CR = CI / RI \quad (2)$$

Achieving a CR value strictly under the 0.10 (10%) threshold conclusively proved internal mathematical consistency, authorizing the weights for immediate empirical deployment.

### 3.4. Field Audit Protocol across Multiple Welding Bays

Applying these theoretical weights into a field assessment protocol, our audit team conducted rigorous physical inspections across three distinct operational zones (Bay A, Bay B, and Bay C) over the course of one academic cycle. Each of the five core pillars was assessed using a structured 0-100 scoring rubric, anchored as follows: 0-20 (Severe Non-compliance), 21-40 (Poor), 41-60 (Marginal), 61-80 (Adequate), and 81-100 (Full Compliance). The assessments were conducted by two independent, certified OHS auditors to ensure objectivity. Interrater reliability was confirmed by comparing independent scores before reaching a final consensus. Multiplying these raw scores by their corresponding AHP weights generated the weighted compliance value, ultimately yielding the overall OHS Index for the institution.

## 4. RESULTS AND DISCUSSION

### 4.1 . Delphi Parameter Consolidation Output

Operating with lethal efficiency, the two-stage Delphi process achieved absolute convergence among the panel members by the conclusion of Round 2. The initially bloated list of twenty disparate variables was systematically shredded and consolidated into five essential OHS pillars. Table II explicitly details these definitive evaluation parameters, alongside their highly specific socio-technical definitions calibrated for a higher vocational context.

| <b>Code</b> | <b>Core OHS Parameter &amp; Contextual Definition</b>                                                                                                              | <b>Consensus (%)</b> |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| C1          | Local Exhaust Ventilation (LEV): Mechanical extraction systems situated at the source of the arc to violently capture fumes before they breach the breathing zone. | 100%                 |
| C2          | Completeness of PPE: Institutional provision and merciless enforcement of auto-darkening helmets, heavy leather aprons, gauntlets, and steel-toe boots.            | 100%                 |

|    |                                                                                                                                                           |     |
|----|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| C3 | SOP Availability: High-visibility, fool-proof, color-coded written safety procedures permanently affixed directly to each welding booth.                  | 95% |
| C4 | Instructor Supervision: The numeric ratio and aggressive physical presence of qualified technicians actively monitoring the floor during shifts.          | 90% |
| C5 | Emergency Response Facilities: Strategic placement and strict verification of dry chemical APAR units, medical trauma kits, and plumbed eyewash stations. | 85% |

#### 4.2. AHP Pairwise Comparison Matrix Data Analysis

Fusing the experts' independent pairwise evaluations via geometric mean aggregation birthed the consolidated 5x5 comparison matrix showcased in Table 3. A row-by-row inspection reveals a clear trend: engineering controls (C1) significantly outweigh both administrative rules and personal protection metrics. For instance, C1 utterly dominates C2 with an intensity score of 3.00, and overpowers C3 with a 2.00. This mathematically cements the panel's consensus regarding infrastructural supremacy.

**Table 3.** Aggregated Expert Pairwise Comparison Matrix

| Crit. | C1   | C2   | C3   | C4   | C5   |
|-------|------|------|------|------|------|
| C1    | 1.00 | 3.00 | 2.00 | 4.00 | 5.00 |
| C2    | 0.33 | 1.00 | 0.50 | 2.00 | 3.00 |
| C3    | 0.50 | 2.00 | 1.00 | 3.00 | 4.00 |
| C4    | 0.25 | 0.50 | 0.33 | 1.00 | 2.00 |
| C5    | 0.20 | 0.33 | 0.25 | 0.50 | 1.00 |

#### 4.3. Criteria Weight Derivation and Mathematical Consistency Test Results

Post-normalization, the matrix yielded its final priority weights (eigenvectors), explicitly detailed in Table 4. Criterion C1 (Local Exhaust Ventilation) emerged as the primary focus with a weight of 0.416, representing 41.6% of the total priority spectrum. Administrative procedural support via C3 (SOP Availability) claimed a distant second at 26.2%, leaving personal physical barriers via C2 (PPE Completeness) languishing in third place at 16.1%.

**Table 4.** Derived AHP Priority Weights

| Code | Core OHS Parameter            | Derived Weight (W) | Rank |
|------|-------------------------------|--------------------|------|
| C1   | Local Exhaust Ventilation     | 0.416              | 1    |
| C3   | Standard Operating Procedures | 0.262              | 2    |
| C2   | Personal Protective Equipment | 0.161              | 3    |
| C4   | Instructor Supervision        | 0.099              | 4    |
| C5   | Emergency Response Facilities | 0.062              | 5    |

Validating these priority numbers required proving internal consistency. Computing the maximum eigenvalue ( $\lambda_{max}$ ) yielded 5.110. Jamming this into Equation (1) alongside  $n = 5$  generated a Consistency Index (CI) of 0.0275. Subsequently dividing this by the standard random index ( $RI = 1.12$ ) via Equation (2) finalized a spectacularly tight Consistency Ratio (CR) of 0.024. Clocking in at a mere 2.4% massively under Saaty's 10% maximum permissible threshold the comparison matrix proved totally devoid of logical contradictions, officially validating the tool for field application.

#### 4.4. Empirical Field Assessment and Gap Analysis

Weaponizing the AHP weights against the raw compliance scores aggressively extracted from three distinct welding bays produced the analytical output summarized in Table 5. The assessment revealed an overall mean OHS Index score of 61.03 out of 100.

**Table 5.** Empirical Multi-Bay Ohs Index And Gap Analysis

| Code     | Weight (W) | Bay Mean Score | Weighted Value | Gap (%) |
|----------|------------|----------------|----------------|---------|
| C1 (LEV) | 0.416      | 50.0           | 20.81          | 50.0    |

|             |       |      |       |       |
|-------------|-------|------|-------|-------|
| C2 (PPE)    | 0.161 | 85.0 | 13.69 | 15.0  |
| C3 (SOP)    | 0.262 | 60.0 | 15.71 | 40.0  |
| C4 (Supv.)  | 0.099 | 75.0 | 7.39  | 25.0  |
| C5 (Emerg.) | 0.062 | 55.0 | 3.43  | 45.0  |
| TOTAL       | 1.000 | -    | 61.03 | 38.97 |

## 4.5. Discussion

### Critical Synthesis of Engineering Controls vs. Dilution Ventilation

Scrutinizing the data reveals a significant gap: Local Exhaust Ventilation (LEV), mathematically certified as the absolute zenith of safety priorities with a 0.416 weight, scored only 50 in the field. This result highlights a structural limitation in how polytechnic facilities are governed. Currently, management operates under the terrifyingly naive assumption that passively cracking open windows and running generic, wall-mounted exhaust fans constitutes an adequate defense against concentrated welding operations.

From an engineering perspective, this reliance on dilution ventilation is worse than useless. Wall fans do not magically erase airborne contaminants; they forcefully drag toxic, heavy-metal-laced fume plumes directly through the breathing zones of unsuspecting students standing twenty feet downwind. As explicitly proven by the field data, legitimate hazard containment requires physically trapping the fumes at the source, mandating the installation of capturing hoods situated a mere 10 to 30 centimeters from the arc ignition point. Only this aggressive extraction method prevents lethal aerosolized particles from dispersing into the wider laboratory atmosphere, effectively shielding both the active operator and collateral bystanders from chronic respiratory decay.

Perhaps the most damning evidence is the terrifying uniformity of this failure across the facility. Evaluating the three separate operational zones revealed a shockingly consistent disregard for engineering controls. Bay A managed a 50. Bay B sank to 45, and Bay C plateaued at 55. Such uniform results suggest a systemic issue rather than an isolated maintenance problem, instead proving a systemic, institutionalized refusal to commit capital towards heavy infrastructure investments.

### The False Security of Administrative Compliance and PPE

Lurking within the dataset is a deeply troubling paradox. The institution proudly secured a highly commendable raw score of 85 for PPE completeness (C2), driven by a draconian shop culture that forces every student into heavy aprons and helmets. Yet, despite this seemingly stellar administrative victory, the overall safety index remained at 61.03. This stark discrepancy perfectly exposes the inherent danger of relying on personal protection and administrative edicts as the primary mechanisms of defense. For notoriously cash-strapped state polytechnics, hoarding crates of cheap leather gloves and plastering the walls with generic warning signs is an incredibly cost-effective method to mimic safety compliance.

However, this strategy is challenging the institution. It entirely shifts the ultimate burden of survival onto the shoulders of an exhausted, inexperienced novice. If a green student momentarily forgets to latch their visor or accidentally wears degraded gauntlets, their physiological protection instantly plummets to absolute zero. After that, strapping a thick leather apron to a student might successfully deflect a glob of molten slag, but it offers zero physiological defense against the invisible, neurotoxic manganese fumes flooding their lungs.

Educational administrators some times face difficulty to internalize a harsh reality: PPE represents the final, desperate line of defense in the hierarchy of controls. Harvesting a high administrative score simply for handing out safety glasses provides a dangerously false sense of security, often used to indefinitely delay massive capital investments in legitimate engineering infrastructure. relentlessly filtering the audit data through the objective lens of AHP, it becomes terrifyingly clear that administrative triumphs frequently mask profoundly unsafe occupational environments.

### Strategic Capital Allocation and Institutional Policy Recommendations

Addressing the identified 38.97% compliance gap and elevating this facility into the realm of acceptable industrial safety demands a radical, uncompromising overhaul of the institution's capital allocation strategy. Executive management must immediately cease hemorrhaging budgets on redundant administrative theater and aggressively pivot towards heavy engineering infrastructure. The absolute, non-negotiable primary

mandate is the immediate procurement and installation of an integrated Local Exhaust Ventilation (LEV) network, demanding that every single welding booth be equipped with a high-vacuum, articulated extraction arm.

Simultaneously, the facility must rectify its profoundly mediocre score for SOP availability (60). To effectively communicate safety procedures in a noisy workshop, administrators should replace dense text with clear, highly visible visual flowcharts affixed directly to the workstations, explicitly acknowledging the limited situational experience of their novice student cohorts. Executing these targeted, data-backed upgrades will not only obliterate future compliance audits but will fundamentally foster a proactive, hyper-vigilant safety culture capable of genuinely protecting human life.

### Limitations of the Study

This study presents several limitations that should be considered. First, the field evaluation was conducted at a single vocational institution across only three welding bays, which may limit the generalizability of the findings to other polytechnics with different infrastructure. Second, the Delphi panel utilized a small sample size ( $n=5$ ); while the experts were highly qualified, a larger or more diverse panel might produce slight variations in consensus weights. Furthermore, as previously noted, hazard claims are strictly literature-based. Future studies should integrate direct air sampling and empirical exposure measurements to complement the risk assessment framework developed in this study.

## 5. CONCLUSION

This research proves that systematically fusing a multi-stage Delphi panel with the combination of the Analytical Hierarchy Process (AHP) creates a highly context-calibrated for implementation of occupational safety in higher vocational engineering workshops. Tearing through subjective bias, the mathematical analysis conclusively made Local Exhaust Ventilation (C1) as the absolute, supreme priority parameter, wielding a dominant, unassailable weight of 0.416. Deploying this custom-built index across multiple bays at a massive polytechnic in Jakarta exposed a terrifyingly vulnerable overall mean OHS score of 61.03. The facility leans dangerously hard on personal protective gear, utilizing it as a crutch to mask severe, uniform gaps in source-ventilation engineering infrastructure. If institutional administrators possess any genuine desire to resolve this vulnerability, they must immediately abandon their obsession with superficial administrative controls. Committing massive capital expenditure towards automated, localized exhaust ventilation networks is the only scientifically valid method to ensure a safe learning environment that actively defends the respiratory health of future technical professionals.

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