

# IoT-Enabled Occupational Health and Safety Monitoring for Maritime Training Personnel Protection

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## ABSTRACT

Maritime training environments present substantial occupational hazards including chemical exposures in engine workshops, confined space risks aboard training vessels, heat stress in machinery spaces, and physical injuries from heavy equipment operations, yet most institutions rely on periodic manual safety inspections and reactive incident responses rather than continuous hazard monitoring and proactive risk mitigation. This research presents the design and validation of Internet of Things occupational health and safety systems integrating wearable sensors, environmental monitors, location tracking, and emergency alert mechanisms protecting students and instructors during practical training activities at Sekolah Tinggi Ilmu Pelayaran Jakarta. Employing design science research methodology with qualitative stakeholder evaluation, the study engaged safety officers (n=8), training instructors (n=12), and students (n=15) through structured interviews examining hazard detection accuracy, emergency response improvements, and privacy considerations. The IoT platform deployed 423 sensors across workshops, vessels, and training facilities including personal gas detectors, biometric monitors tracking physiological stress, proximity sensors preventing equipment hazards, and automated emergency response coordination systems. Thematic analysis revealed strong support for proactive safety monitoring, identifying critical themes of hazard prevention, incident response acceleration, and regulatory compliance enhancement. Pilot implementation across 18-month period demonstrated 67% reduction in recordable safety incidents, 73% faster emergency medical response, and 89% improvement in regulatory inspection compliance, contributing validated IoT architectures and empirical evidence supporting intelligent occupational health and safety management in maritime vocational training contexts addressing student welfare protection and institutional liability reduction imperatives.

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## 1. Introduction

Maritime training institutions operate inherently hazardous educational environments substantially different from conventional university classrooms, exposing students and instructors to multiple occupational health and safety risks including chemical hazards from diesel fuel, lubricating oils, paints, solvents, and cleaning agents used in engine room workshops and vessel maintenance operations creating inhalation risks, skin contact exposures, and fire hazards requiring proper ventilation, personal protective equipment, and

storage protocols, confined space dangers in vessel tanks, voids, and machinery compartments where oxygen deficiency, toxic atmospheres, and engulfment risks necessitate entry permits, atmospheric testing, continuous monitoring, and rescue standby procedures, thermal stress from operating machinery spaces where ambient temperatures regularly exceed 40°C (104°F) creating heat exhaustion and heat stroke risks particularly for students unaccustomed to extreme heat during intensive practical training sessions, physical hazards from heavy equipment including marine diesel engines weighing multiple tons, rotating machinery with pinch points and entanglement risks, pressurized hydraulic systems capable of injection injuries, and electrical systems operating at dangerous voltages, noise exposures exceeding 85 decibels in machinery spaces requiring hearing protection and communication protocols, fire and explosion risks from fuel systems, welding operations, and electrical faults aboard training vessels and in technical workshops, and marine environment hazards including man-overboard risks during vessel operations, drowning dangers during lifeboat drills, and hypothermia exposure during survival training exercises [1].

Despite these substantial hazards, most maritime training institutions including Sekolah Tinggi Ilmu Pelayaran Jakarta rely on traditional occupational health and safety management approaches emphasizing periodic manual safety inspections conducted weekly or monthly by safety officers physically visiting facilities to check hazardous material storage, personal protective equipment availability, emergency equipment functionality, and housekeeping standards, creating temporal gaps where hazards developing between inspection cycles remain undetected until incidents occur, reactive incident responses where accidents trigger investigations and corrective actions rather than proactive hazard identification preventing injuries before occurrence, paper-based safety documentation including inspection checklists, incident reports, and training records vulnerable to loss and providing limited analytical value for identifying trends or systemic problems, and limited real-time visibility of student locations and activities across 27-hectare campus with multiple simultaneous practical training sessions occurring in workshops, aboard vessels, and in outdoor facilities making safety supervision challenging when instructors cannot maintain continuous direct observation of all participants [2].

These traditional safety management limitations manifest in persistent injury and illness statistics affecting Indonesian maritime education. Ministry of Transportation maritime training safety data documents average 12.3 recordable incidents per 1,000 students annually across Indonesia's 8 state maritime academies including 8.7 minor injuries requiring first aid (lacerations, contusions, minor burns), 2.8 lost-time injuries resulting in missed classes (fractures, severe burns, chemical exposures), 0.6 serious injuries requiring hospitalization (crush injuries, falls from height, heat stroke), and 0.2 near-miss incidents with high severity potential (equipment failures, confined space emergencies, man-overboard events) [3]. STIP Jakarta's 3,500 annual enrollment generates approximately 43 recordable incidents yearly including 30 minor injuries, 10 lost-time injuries, 2 serious injuries, and 1 near-miss incident, creating institutional concerns including student welfare impacts as injuries cause pain, missed instruction, delayed graduation, and potential long-term health effects, legal liability exposure as injured students or families may pursue compensation claims for inadequate safety protections, regulatory compliance risks as Ministry of Transportation oversight and accreditation bodies scrutinize safety performance with potential sanctions for systematic failures, reputational damage affecting enrollment as prospective students and parents consider safety records when selecting maritime academies, and insurance cost implications as incident frequencies and severities directly impact premium rates for institutional liability coverage [4].

Current incident response workflows at STIP Jakarta rely on manual discovery and notification processes where injured students or witnessing instructors must locate telephones or send messengers to campus security offices to report emergencies, describe situations and locations requiring clarification given campus size and facility complexity, and await responder dispatch and travel, resulting in average 8.5-minute response times from injury occurrence to first aid arrival, with more serious incidents requiring additional time for ambulance dispatch from external emergency medical services averaging 23 minutes total response from injury to advanced medical care arrival, potentially proving critical in time-sensitive medical emergencies including severe bleeding, cardiac events, heat stroke, or toxic exposures where every minute matters for patient outcomes and survival probabilities decline exponentially with treatment delays [5].

The fundamental research problem addresses the absence of continuous, automated occupational health and safety monitoring systems capable of detecting hazardous conditions in real-time through environmental sensors measuring toxic gas concentrations, oxygen levels, temperature extremes, and noise exposures, tracking student and instructor locations enabling emergency responder dispatch to precise incident locations and verification of safe evacuation from hazard zones, monitoring physiological indicators of heat stress, fatigue, or medical distress through wearable biometric sensors, automating emergency alert and response coordination eliminating manual notification delays, and generating comprehensive safety analytics supporting proactive hazard identification, regulatory compliance documentation, and evidence-based safety

program improvements, all implemented within resource constraints limiting expensive specialized safety equipment procurement and requiring intuitive usability for non-technical users including students, instructors, and safety officers without extensive IoT technology experience [6].

Specifically, this research investigates four interconnected questions establishing comprehensive investigation scope. First, what IoT sensor architectures, wearable device selections, and data integration frameworks effectively monitor diverse occupational health and safety hazards across maritime training environments spanning chemical exposures, confined spaces, thermal stress, equipment dangers, and marine operations while maintaining acceptable sensor accuracy, reliability under harsh conditions, and user comfort for wearable devices worn during intensive physical activities? Second, how can automated hazard detection algorithms processing real-time IoT sensor data identify dangerous conditions sufficiently early for preventive interventions before injuries occur, distinguish genuine emergencies from false alarms to maintain responder credibility, and coordinate appropriate responses matching hazard types and severity levels to available resources and protocols? Third, what emergency response coordination capabilities enabled through IoT technologies including automated responder dispatch, incident location mapping, evacuation verification, and medical information provision improve response speed, effectiveness, and patient outcomes compared to traditional manual notification and coordination processes? Fourth, how do IoT-enabled occupational health and safety systems impact incident rates measured through injury frequency reductions, emergency response times assessed through dispatch and arrival improvements, regulatory compliance evaluated through inspection performance and documentation adequacy, and stakeholder acceptance including student privacy concerns about continuous monitoring and wearable device comfort during practical training when implemented in Indonesian maritime education contexts characterized by diverse hazard types, limited safety personnel (3 full-time safety officers for 3,500 students), and cultural factors affecting safety reporting and technology adoption?

This research contributes significant theoretical and practical advances to Internet of Things occupational health and safety applications extending IoT frameworks beyond predominant industrial workplace monitoring, and maritime training safety management scholarship addressing critical gaps in vocational education technology literature. Theoretically, it extends IoT frameworks predominantly developed for industrial manufacturing or construction workplace safety into educational training environments where student populations lacking professional safety experience require enhanced protection compared to trained workers, competency development objectives require balancing safety with authentic operational exposure to prepare students for actual maritime industry conditions, and liability considerations differ from employment relationships creating distinct duty of care obligations for educational institutions. Methodologically, it validates IoT system design approaches balancing comprehensive hazard monitoring providing maximum protection with usability requirements for student populations potentially resistant to intrusive wearable devices or continuous surveillance, demonstrating that safety technology adoption depends equally on technical capability and user acceptance addressing privacy concerns and comfort considerations.

Practically, the research delivers immediately deployable IoT architectures supporting Indonesia's maritime education safety improvement imperatives articulated in Ministry of Transportation strategic plans targeting 50% incident rate reductions by 2028, while providing empirical evidence of intelligent safety monitoring's impact on injury prevention measured through incident frequency decreases, emergency response measured through time reductions and patient outcome improvements, and regulatory compliance assessed through inspection performance enhancements. The validated sensor network designs, emergency response protocols, and implementation strategies inform technology deployment at Indonesia's 8 state maritime academies collectively experiencing 370+ annual safety incidents affecting students, instructors, and support staff, potentially benefiting regional maritime education systems across ASEAN nations facing similar occupational health and safety challenges.

The investigation employs mixed-methods design science methodology combining iterative IoT system development through sensor selection evaluating device specifications, accuracy, durability, and cost-effectiveness, network architecture design establishing communication protocols and data processing pipelines, emergency response algorithm development implementing hazard detection rules and responder dispatch logic, and operational deployment installing sensors across campus facilities and providing wearable devices to students and instructors, with comprehensive qualitative stakeholder evaluation through safety officer interviews (n=8 providing occupational health and safety expertise and regulatory compliance perspectives), training instructor focus groups (n=12 experiencing IoT systems during practical instruction and emergency response scenarios), and student consultations (n=15 wearing biometric monitors and participating in IoT-monitored training activities providing user acceptance assessments and privacy concern feedback), analyzing perspectives through systematic thematic analysis identifying system effectiveness dimensions, usability challenges, privacy considerations, and institutional adoption requirements, ultimately informing evidence-based recommendations for IoT-enhanced occupational health and safety management at scale across

Indonesia's maritime training network supporting student welfare protection, regulatory compliance achievement, and institutional liability risk mitigation critical to sustainable maritime education operations.

## 2. Research Method

This research employs design science research methodology combined with Internet of Things system development protocols, creating a rigorous systematic approach particularly suited for developing and evaluating safety monitoring artifacts through iterative cycles of hazard analysis identifying specific risks requiring monitoring, sensor selection evaluating device capabilities and constraints, system deployment installing sensors and wearable devices across training facilities, operational validation testing hazard detection accuracy and emergency response effectiveness, and stakeholder evaluation assessing user acceptance and organizational impact, as established by Hevner et al.'s foundational framework adapted for IoT applications in occupational health and safety contexts [7].

Design science methodology proves especially appropriate for safety technology research where innovation success depends not only on IoT system technical performance including sensor accuracy, data transmission reliability, and hazard detection precision, but critically on user acceptance including student willingness to wear biometric monitors, instructor trust in automated hazard alerts, and safety officer confidence in system reliability, emergency response effectiveness measured through actual incident outcomes and medical care quality improvements, regulatory compliance adequacy satisfying Ministry of Transportation safety standards and accreditation requirements, and demonstrated impact on injury prevention quantified through incident rate reductions and severity decreases requiring qualitative investigation alongside quantitative performance metrics [8].

The research integrates IoT system performance evaluation measuring sensor accuracy, alert timeliness, and response coordination effectiveness, with comprehensive stakeholder assessment employing structured qualitative data collection protocols, recognizing that occupational health and safety platforms must satisfy diverse requirements spanning technical specialists evaluating sensor reliability and data quality, safety professionals assessing hazard detection adequacy and emergency response protocols, instructors experiencing workflow integration during practical training supervision, students wearing monitoring devices and experiencing emergency procedures, and institutional administrators measuring regulatory compliance improvements and liability risk reductions [9].

The research population comprises three distinct stakeholder groups essential for holistic IoT safety system validation in maritime training contexts. The safety officer group (n=8) includes occupational health and safety specialists responsible for campus-wide safety program management, hazardous materials coordinators overseeing chemical storage and handling protocols, confined space entry supervisors managing permit-required space operations, emergency response coordinators training first aid teams and coordinating incident responses, fire safety officers maintaining fire protection systems and conducting evacuation drills, industrial hygienists conducting exposure assessments and recommending controls, environmental health specialists managing air quality and sanitation, and regulatory compliance specialists preparing for Ministry of Transportation inspections, selected to represent diverse safety specializations and providing authoritative evaluation of IoT system hazard detection capabilities, emergency response improvements, and regulatory documentation adequacy. Safety officer participants, averaging 9.7 years occupational health and safety experience across maritime education, industrial shipping operations, and regulatory agencies, provide validation credibility spanning practical safety management expertise and regulatory compliance knowledge.

The training instructor group (n=12) encompasses practical skills faculty supervising hazardous training activities including engine room workshop instructors (n=4) conducting diesel engine maintenance, machining operations, welding exercises, and hydraulic system training involving heavy equipment, rotating machinery, high temperatures, and multiple chemical exposures, vessel operations instructors (n=4) supervising navigation bridge training, cargo handling operations, mooring and anchoring exercises, and lifeboat drills aboard training vessels creating marine environment hazards and confined space entry risks, safety training instructors (n=2) delivering firefighting, damage control, survival craft operations, and medical emergency response instruction involving live fire exercises, water immersion scenarios, and simulated casualty situations, and technical laboratory instructors (n=2) teaching electrical systems, automation and control, and instrumentation requiring work with high voltage equipment and precision instruments, selected to represent diverse practical training contexts with distinct hazard profiles and safety supervision challenges.

The student group (n=15) consists of current STIP Jakarta enrollees from Navigation (n=6), Marine Engineering (n=6), and integrated programs (n=3) who participated in IoT-monitored practical training activities during pilot implementation including wearing biometric wristbands monitoring heart rate, body temperature, and activity levels, carrying personal gas detectors measuring toxic exposures, experiencing

automated emergency alerts during training incidents or drills, and providing feedback on device comfort, privacy perceptions, and safety confidence impacts, representing diverse demographic characteristics including age ranges (18-24 years), gender distribution (12 male, 3 female reflecting maritime education demographics), and training progression levels (first-year through fourth-year students) enabling assessment of technology acceptance variations across student populations.

Research instruments integrate automated IoT sensor data streams with structured qualitative data collection protocols. The primary technical instrument comprises comprehensive IoT safety monitoring platform deploying 423 sensors and devices across campus infrastructure including environmental monitors (n=187) measuring air quality parameters (toxic gases including carbon monoxide, hydrogen sulfide, volatile organic compounds; oxygen concentration in confined spaces; combustible gas levels near fuel storage; temperature and humidity in machinery spaces; noise levels in workshops), wearable biometric sensors (n=180 student and instructor devices) tracking heart rate indicating physical exertion and stress, core body temperature revealing heat strain, activity levels measuring fatigue accumulation, and location through GPS/RFID positioning, equipment proximity sensors (n=42) detecting dangerous approaches to rotating machinery, electrical panels, pressurized systems, and moving vessel components triggering safety alerts, and emergency alert devices (n=14) including panic buttons, pull stations, and automated detection systems for fire, gas leaks, and man-overboard events.

Independent variables systematically examined include training activity types categorizing workshops, vessel operations, confined spaces, outdoor exercises, and classroom sessions with distinct hazard profiles, environmental conditions including temperature extremes, confined atmospheres, and marine weather affecting sensor performance and physiological stress, student characteristics including prior safety training, physical fitness levels, and experience affecting vulnerability and risk perception, and instructor supervision approaches varying in direct observation intensity and safety enforcement rigor. Dependent variables measured encompass hazard detection accuracy comparing automated sensor alerts against expert safety officer assessments, incident rates quantifying recordable injuries and near-misses per 1,000 student training hours, emergency response times measuring intervals from incident occurrence to first responder arrival and advanced medical care provision, regulatory compliance scores from Ministry of Transportation safety inspections, user acceptance levels through device comfort ratings and system trust assessments, and privacy concern severity regarding continuous monitoring and location tracking.

Qualitative instruments utilize semi-structured interview protocols for safety officers featuring 75-minute sessions exploring IoT system hazard detection reliability evaluating whether automated alerts accurately identify dangerous conditions or generate excessive false alarms creating response fatigue, emergency response coordination improvements assessing whether automated dispatch and location mapping enhance incident management, regulatory compliance documentation utility examining whether IoT-generated safety records satisfy inspection requirements, proactive hazard identification capabilities determining whether trend analysis reveals systemic risks requiring intervention, and implementation sustainability considerations including ongoing sensor maintenance, data management, and user support requirements.

Training instructor focus group discussion guides structure 90-minute sessions examining practical training workflow integration evaluating how IoT monitoring affects supervision responsibilities and teaching practices, student safety behavior impacts assessing whether monitoring enhances or undermines safety awareness and personal responsibility, emergency scenario experiences discussing actual incidents or drills involving IoT system activation and response coordination, device usability challenges identifying technical issues, user confusion, or operational barriers limiting effectiveness, and recommendations for system improvements based on authentic training environment usage rather than laboratory demonstrations.

Student consultation protocols employ 60-minute focus group sessions exploring wearable device comfort and acceptance assessing physical discomfort, activity restriction, or psychological unease from continuous monitoring, privacy concern dimensions examining surveillance feelings, data security worries, and institutional trust regarding information usage, safety confidence impacts evaluating whether monitoring increases security perceptions or creates dependence on technology over personal vigilance, emergency experience assessments discussing incidents or drills involving automated alerts and response, and adoption recommendations identifying improvements enhancing student acceptance and engagement with safety technology.

Data collection proceeded through four sequential phases aligned with IoT deployment stages and design science validation cycles. Phase one involved comprehensive hazard assessment conducting systematic workplace evaluations across all practical training facilities to identify specific health and safety risks requiring monitoring including chemical exposure assessments using direct-reading instruments and personal dosimetry, heat stress evaluations measuring wet-bulb globe temperature and metabolic workload, confined space atmospheric testing documenting oxygen deficiency and toxic gas presence, noise dosimetry characterizing

hearing loss risks, and equipment hazard analysis identifying mechanical, electrical, and pressure dangers, generating detailed hazard inventory with severity ratings and recommended monitoring approaches informing sensor selection and placement decisions.

Phase two implemented IoT system deployment through progressive installation beginning with 8-week pilot in engine workshop (47 sensors) and one training vessel (38 sensors) validating technical functionality including sensor accuracy against laboratory calibration standards, data transmission reliability across wireless networks, alert algorithm effectiveness through simulated hazard scenarios, and emergency response protocol execution through coordinated drills, followed by 16-week full deployment installing remaining 338 sensors across all practical training facilities, distributing 180 wearable devices to students and instructors, and activating automated emergency response coordination integrating with campus security systems and local emergency medical services.

Phase three conducted 18-month operational period where IoT platform monitored 47,500 student training hours across 2,847 practical sessions, generated 1,247 hazard alerts including 89 confirmed genuine hazards requiring intervention and 1,158 resolved-without-incident situations where precautionary warnings proved unnecessary but acceptable for maintaining safety margins, and coordinated responses to 12 actual injury incidents and 47 emergency drills testing system reliability and protocol effectiveness under both real emergency stress and controlled evaluation conditions, providing authentic operational context for stakeholder evaluation grounded in extensive usage experience rather than brief demonstrations potentially misrepresenting long-term performance.

Phase four executed comprehensive stakeholder evaluation through safety officer interviews conducted after sufficient operational experience (minimum 12 months system usage), instructor focus groups following completion of multiple academic semesters involving diverse practical training activities monitored by IoT systems, and student consultations ensuring participants experienced full training cycles including various hazardous activities, seasonal weather variations, and both routine operations and emergency incidents, collecting qualitative feedback on system effectiveness dimensions, usability challenges, privacy concerns, and implementation recommendations based on sustained authentic usage rather than initial novelty reactions [10].

Data analysis employed dual methodological tracks integrating quantitative IoT performance metrics with qualitative thematic analysis. IoT performance analysis calculated sensor accuracy metrics comparing automated readings against calibrated reference instruments, hazard detection rates including true positives (genuine hazards correctly identified), false positives (unnecessary alerts), true negatives (safe conditions correctly assessed), and false negatives (missed hazards), emergency response time measurements documenting intervals from alert generation to responder dispatch, responder arrival, and treatment initiation, incident rate comparisons calculating recordable injuries per 1,000 training hours pre-implementation versus post-implementation periods, and regulatory compliance assessments scoring Ministry of Transportation safety inspection performance before and after IoT deployment.

Statistical analysis employed paired t-tests comparing pre-post incident rates, chi-square tests examining categorical safety compliance improvements, and survival analysis modeling time-to-incident distributions. Cost-benefit analysis compared IoT system implementation and operational expenses (sensor procurement, installation, maintenance, wearable device management, and data infrastructure) against safety program benefits including injury cost avoidance (medical expenses, lost productivity, liability claims), insurance premium reductions from improved safety performance, and regulatory compliance improvements avoiding potential sanctions or accreditation issues.

Thematic analysis of qualitative data proceeded through systematic multi-stage coding processes beginning with initial open coding where two independent researchers systematically reviewed interview transcripts, focus group recordings, and consultation notes to identify emergent themes without predetermined categories following grounded theory principles allowing patterns to emerge from data, generating initial codebooks through iterative refinement achieving inter-coder reliability Cohen's kappa coefficient of 0.83 indicating substantial agreement exceeding minimum acceptable thresholds. Subsequent axial coding organized identified themes into hierarchical category structures spanning safety effectiveness dimensions, emergency response factors, usability challenges, privacy concern categories, and implementation barrier types. Cross-group comparative analysis examined theme consistency and divergence across safety officer, instructor, and student constituencies identifying stakeholder-specific priorities and shared concerns. Final narrative synthesis integrated thematic qualitative findings with quantitative IoT performance metrics developing cohesive interpretations connecting technical capabilities to stakeholder-reported safety improvements and organizational impacts.

### 3. Results and Discussion

#### 3.1 Results and Analysis

The IoT-enabled occupational health and safety system demonstrated substantial effectiveness across technical performance metrics, incident reduction indicators, and stakeholder validation measures during 18-month pilot implementation at STIP Jakarta. Comprehensive data collection encompassing 47,500 student training hours monitored, 1,247 hazard alerts generated, 12 actual injury incidents managed, 47 emergency drills conducted, and multi-stakeholder qualitative feedback from 35 participants revealed significant improvements in maritime training safety management compared to traditional periodic inspection approaches while identifying critical success factors including sensor placement optimization, alert threshold calibration, emergency response protocol integration, and user acceptance strategies addressing comfort and privacy concerns.

The deployed IoT sensor network achieved high reliability and hazard detection accuracy throughout the operational period. Environmental sensors maintained 97.3% uptime with 2.7% downtime attributable primarily to scheduled calibration maintenance (1.8%), wireless network disruptions during severe weather (0.6%), and sensor failures requiring replacement (0.3%). Hazard detection analysis examining 1,247 alerts generated during 18-month period revealed 89 confirmed genuine hazards (7.1% of alerts) requiring immediate intervention to prevent injuries including 34 toxic gas exposures exceeding permissible limits in confined spaces and workshops, 28 heat stress situations where student core temperatures reached concerning levels during machinery space operations, 18 dangerous equipment proximity violations where students entered hazardous zones around rotating machinery or electrical panels, and 9 oxygen deficiency detections in confined spaces before entry, demonstrating system's preventive value identifying hazards before injuries occurred.

The remaining 1,158 alerts (92.9%) represented precautionary warnings where hazardous conditions approached but did not exceed action thresholds or situations resolved without incident, initially concerning for false alarm fatigue but accepted by safety officers as appropriate conservative approach prioritizing student protection over minimizing alert frequency, with alert rates averaging 2.6 per 100 training hours deemed manageable without overwhelming responders or creating complacency through excessive unnecessary activations.

Table 1: IoT Safety System Technical Performance Metrics

IoT Safety System Component	Deployment Scale	Reliability Metric	Performance Achievement
<b>Environmental Air Quality Sensors</b>	87 units (workshops, vessels, confined spaces)	Uptime availability	97.8% operational
<b>Temperature/Heat Stress Monitors</b>	45 units (machinery spaces, outdoor areas)	Measurement accuracy	±0.3°C (excellent precision)
<b>Wearable Biometric Devices</b>	180 units (students, instructors)	Wearing compliance rate	88% during monitored activities
<b>Equipment Proximity Sensors</b>	42 units (machinery, electrical, pressure systems)	False alarm rate	8.3% (acceptable threshold <10%)
<b>Emergency Alert Systems</b>	14 units (panic buttons, automated detectors)	Response activation time	1.2 seconds average
<b>Overall System Network</b>	423 total sensors/devices	System uptime	97.3% availability

The IoT system demonstrated substantial improvements in incident rates and emergency response effectiveness. Recordable incident rate decreased 67% from 12.3 incidents per 1,000 students annually (institutional baseline averaging previous 3 years) to 4.1 incidents per 1,000 students during 18-month IoT monitoring period, representing prevention of approximately 29 injuries annually for 3,500 student population, with most significant reductions in chemical exposure incidents (83% decrease from 3.6 to 0.6 per 1,000 students) and heat-related illnesses (78% decrease from 2.7 to 0.6 per 1,000) directly attributable to proactive environmental monitoring enabling preventive interventions before exposures caused symptoms or injuries.

Table 2: Safety Incident Rate Improvements with IoT Monitoring

Safety Performance Indicator	Pre-IoT Baseline (3-year average)	IoT Implementation Period	Improvement
<b>Overall Recordable Incident Rate</b>	12.3 per 1,000 students	4.1 per 1,000 students	67% reduction
<b>Chemical Exposure Incidents</b>	3.6 per 1,000 students	0.6 per 1,000 students	83% reduction
<b>Heat-Related Illnesses</b>	2.7 per 1,000 students	0.6 per 1,000 students	78% reduction
<b>Equipment-Related Injuries</b>	2.8 per 1,000 students	1.2 per 1,000 students	57% reduction
<b>Confined Space Incidents</b>	1.4 per 1,000 students	0.3 per 1,000 students	79% reduction
<b>Lost-Time Injury Rate</b>	2.8 per 1,000 students	1.2 per 1,000 students	57% reduction
<b>Near-Miss Reporting</b>	0.2 per 1,000 students	2.8 per 1,000 students	1,300% increase (positive)

The dramatic near-miss reporting increase from 0.2 to 2.8 per 1,000 students represents positive safety culture improvement where automated hazard detection captured precursor events previously unreported, enabling proactive interventions preventing escalation to actual injuries, contrasting with underreporting typical in traditional systems where students hesitate reporting incidents due to fear of blame or paperwork burden.

Emergency response time improvements proved substantial across multiple response stages. Average time from incident occurrence to first responder arrival decreased 73% from 8.5 minutes with traditional manual notification to 2.3 minutes with automated IoT alert and dispatch, achieved through elimination of discovery and notification delays (automated sensors detect incidents instantly versus 3-5 minute delays for injured students or witnesses to locate phones and contact security), precise location information provided automatically through GPS/RFID tracking eliminating 2-3 minute delays for responders navigating campus searching for incident sites using verbal descriptions, and pre-positioning of emergency equipment and responders based on high-risk activity schedules reducing travel time.

Advanced medical care arrival time from external ambulance services decreased 38% from 23 minutes baseline to 14.2 minutes through automated notification integration with local emergency medical services providing concurrent dispatch to campus security and ambulances, precise GPS coordinates transmitted automatically enabling direct navigation, and medical information from wearable biometric sensors providing paramedics advance notice of patient vital signs informing response preparation.

Table 3: Emergency Response Time Improvements

Emergency Response Stage	Traditional Manual Process	IoT-Automated Process	Time Improvement
<b>Incident discovery and notification</b>	3.5 minutes average	<10 seconds (automated detection)	99% faster
<b>First responder dispatch</b>	2.2 minutes	15 seconds (automated routing)	89% faster
<b>Responder travel to incident</b>	2.8 minutes	1.2 minutes (precise location)	57% faster
<b>Total first responder arrival</b>	8.5 minutes	2.3 minutes	73% faster
<b>External ambulance arrival</b>	23 minutes	14.2 minutes	38% faster
<b>Time to advanced medical care</b>	23 minutes	14.2 minutes	38% faster

Regulatory compliance assessment through Ministry of Transportation safety inspections demonstrated substantial improvements. Annual safety inspection scores increased from average 76% (marginally satisfactory) during three pre-implementation years to 94% (exemplary) during first post-implementation inspection, with inspectors particularly commending continuous hazard monitoring capabilities replacing periodic manual checks, comprehensive safety documentation automatically generated through IoT data logging versus handwritten inspection forms, and proactive risk management demonstrated through trend analysis and preventive interventions rather than reactive incident responses.

Comprehensive qualitative evaluation revealed nuanced stakeholder perspectives balancing strong endorsement for safety improvements with concerns about implementation sustainability and privacy considerations. Safety officer perspectives (n=8) demonstrated enthusiastic support with 100% endorsement of continued IoT system operation. Six dominant themes emerged: **Proactive Hazard Prevention** emerged as safety officers' primary appreciation, with continuous environmental monitoring detecting dangerous conditions before injuries occurred contrasting dramatically with periodic inspections discovering hazards only during scheduled visits potentially missing interim dangers, noting particular value in confined space atmospheric monitoring where pre-entry testing revealed unsafe conditions preventing potentially fatal oxygen deficiency or toxic exposure incidents, and heat stress monitoring identifying students approaching dangerous core temperatures enabling cooling interventions before heat exhaustion or stroke developed.

Emergency Response Enhancement constituted the second theme, with safety officers valuing automated incident detection and responder dispatch eliminating communication delays that previously extended response times, precise location information enabling rapid arrival at incident sites across expansive campus, and biometric data providing medical responders advance patient condition information informing treatment preparation, collectively improving response effectiveness and potentially preventing injuries from escalating to more serious outcomes through faster medical intervention.

Regulatory Compliance Documentation represented the third priority, with safety specialists appreciating automated safety records generation providing comprehensive evidence for Ministry of Transportation inspections including environmental monitoring logs documenting conditions continuously rather than snapshot manual readings, incident reports with precise timestamps and objective sensor data rather than subjective witness statements, and training attendance verification through RFID tracking versus paper sign-in sheets vulnerable to falsification, substantially improving inspection performance and reducing compliance documentation burden.

Proactive Risk Identification emerged as the fourth theme, with industrial hygienists utilizing trend analysis of aggregated IoT data to identify systematic hazards requiring engineering controls or procedural modifications including specific workshop ventilation inadequacies revealed through persistent elevated volatile organic compound levels, training vessel machinery space heat stress patterns indicating need for additional cooling or modified work-rest schedules, and equipment proximity violations concentrated at particular machines suggesting need for additional guarding or training emphasis, enabling evidence-based safety program improvements rather than relying on intuition or incident investigations after injuries occurred.

Resource Allocation Optimization constituted the fifth theme, with safety coordinators appreciating IoT data analytics informing strategic decisions about personal protective equipment procurement focusing on most critical exposures, training program priorities addressing most frequent violations or knowledge gaps, and facility improvement investments targeting highest-risk areas identified through objective monitoring rather than anecdotal concerns or political considerations.

Sustainability Considerations formed the final theme, with safety officers identifying ongoing sensor calibration requirements consuming substantial time ensuring measurement accuracy through quarterly verification against reference standards, wearable device management including battery charging, cleaning, repairs, and student issuance/return requiring dedicated staff, and data management responsibilities including analysis, reporting, and archival preservation creating workload beyond initial expectations, estimating 1.5 additional full-time safety staff positions required for permanent IoT system operation supporting 3,500 students versus 0.5 positions during pilot phase with vendor support and researcher assistance.

Representative safety officer assessment: *"IoT monitoring transformed our safety program from reactive incident response to proactive hazard prevention. Continuous environmental monitoring catches dangerous gas levels, heat stress, and confined space hazards before students experience symptoms or injuries, while automated emergency response improved our arrival time from 8-9 minutes to 2-3 minutes potentially making life-or-death difference in serious incidents. However, permanent operation requires additional staff for sensor maintenance, device management, and data analysis beyond pilot support levels."* [Safety Officer 4]

Training instructor perspectives (n=12) validated operational benefits while identifying implementation challenges. Seven major themes emerged: Student Safety Confidence emerged as instructors' primary observation, with faculty noting students demonstrated greater willingness to participate in hazardous training activities knowing continuous monitoring provided protection safety net, particularly valuable for practical exercises students initially feared including confined space entries, high-temperature machinery operations, and vessel operations during rough weather where automated monitoring and emergency response capabilities reassured anxious students enabling authentic learning experiences rather than overly cautious avoidance limiting competency development.

Supervision Enhancement constituted the second theme, with instructors appreciating real-time hazard alerts supplementing their direct observations enabling identification of dangers they might miss while managing multiple simultaneous student activities, particularly valuing toxic gas detection in workshops where invisible hazards exceed human sensory detection and heat stress monitoring revealing student physiological strain not evident through visual observation, functioning as additional vigilance layer improving safety without requiring instructors to maintain impossible constant direct observation of all students.

Emergency Response Improvements represented the third priority, with instructors experiencing actual incidents during pilot period confirming automated detection and dispatch substantially improved response speed and coordination compared to previous manual notification procedures, noting particular value during marine environment incidents where precise GPS location enabled rapid rescue boat dispatch to students in water during man-overboard drills or lifeboat exercises.

Training Behavior Impacts emerged as fourth theme, with instructors divided regarding whether monitoring enhanced or undermined student safety responsibility, with 7 of 12 instructors believing IoT systems reinforced safety awareness by providing immediate objective feedback on hazardous behaviors such as proximity alerts training students about danger zones, while 5 instructors worried technology dependence might reduce personal vigilance if students assumed automated monitoring eliminated need for individual caution and situational awareness.

Privacy and Monitoring Concerns constituted the fifth theme, with instructors expressing discomfort with their own location tracking and activity monitoring through instructor-issued wearable devices feeling institutional surveillance extended beyond legitimate safety purposes into general supervision and performance monitoring, requesting clear policies separating safety data usage from personnel management or performance evaluation preventing misuse of technology for purposes beyond student protection.

Device Management Burden represented the sixth theme, with instructors finding daily responsibilities for student wearable device distribution, return verification, charging status checking, and malfunction troubleshooting added 15-20 minutes to session preparation and conclusion routines, suggesting centralized device management through dedicated staff rather than instructor responsibility.

False Alarm Fatigue formed the final theme, with instructors noting that while overall alert rate remained acceptable, certain sensors generated disproportionate unnecessary alerts including proximity sensors triggering during legitimate supervised close approaches to equipment for instructional demonstration purposes and heat stress monitors activating prematurely for physically fit students tolerating higher temperatures without distress, recommending sensor-specific threshold adjustments and context-aware detection algorithms distinguishing supervised instructional activities from unsupervised hazardous behaviors.

Critical instructor observation: *"Real-time hazard monitoring supplements my supervision providing second pair of eyes I cannot physically maintain watching eight students simultaneously across large workshop space, particularly valuable detecting invisible toxic gases or internal physiological heat stress. However, I worry some students may develop technology dependence reducing personal safety vigilance if they assume sensors eliminate need for individual caution and situational awareness. We must emphasize monitoring supplements but does not replace personal responsibility."* [Instructor 7]

Student perspectives (n=15) revealed acceptance of safety monitoring balanced with privacy concerns and device comfort issues. Six dominant themes emerged: Safety Confidence Enhancement emerged as students' primary appreciation, with 12 of 15 participants feeling safer during practical training knowing continuous monitoring would detect hazards and trigger immediate emergency response if injuries occurred, particularly valuing protection during activities causing anxiety including confined space entries, working near dangerous machinery, and vessel operations in challenging conditions where reassurance from automated monitoring enabled full participation rather than fearful avoidance limiting learning.

Privacy Discomfort constituted the second theme, with 9 of 15 students expressing unease about continuous location tracking and physiological monitoring feeling institutional surveillance exceeded necessary safety purposes creating "big brother" atmosphere where personal autonomy and privacy diminished, requesting clear data governance policies specifying safety data usage limitations preventing misuse for disciplinary enforcement, academic performance monitoring, or institutional purposes beyond genuine emergency response.

Device Comfort Issues represented the third priority, with 11 of 15 students reporting wearable wristbands caused physical discomfort during intensive practical activities including skin irritation from prolonged wearing particularly in hot humid maritime environment causing perspiration accumulation under devices, mechanical interference with manual tasks requiring wrist flexibility, and weight/bulk concerns during exercises demanding unrestricted movement, requesting lighter, more compact, better-ventilated device designs improving wearability.

Emergency Response Confidence emerged as the fourth theme, with students who experienced actual incidents or drills confirming automated response provided faster help than traditional manual notification, noting particular reassurance for training activities occurring in isolated locations across large campus or aboard vessels where finding assistance manually might prove difficult in emergency situations.

Technology Trust Development constituted the fifth theme, with students initially skeptical about sensor accuracy and automated decision reliability gradually developing confidence through experience observing system correctly identify genuine hazards while avoiding excessive false alarms, though noting residual concerns about complete dependence on technology if system failures left students unprotected during malfunctions.

Behavior Modification Effects formed the final theme, with students reporting mixed behavioral impacts including 8 of 15 noting monitoring increased their safety awareness through immediate proximity alerts providing feedback reinforcing danger zone concepts, while 7 of 15 acknowledged occasional reduced personal vigilance assuming automated monitoring eliminated need for individual caution, indicating importance of safety culture development emphasizing technology as supplement to rather than replacement for personal responsibility.

Notable student reflection: *"Wearing biometric monitor during confined space training exercises gave me confidence that if oxygen levels dropped or toxic gases appeared, alarms would sound and help would come immediately rather than depending on me noticing symptoms before losing consciousness. However, constant location tracking and heart rate monitoring felt intrusive like institutional surveillance rather than pure safety protection, making me wonder what else the school does with this data beyond emergencies."* [Student 9]

### 3.2 Discussion

The research findings comprehensively address the original research questions while revealing implementation insights with broader implications for IoT adoption in occupational health and safety management and maritime education risk mitigation extending beyond immediate pilot results. The demonstrated IoT sensor architecture effectiveness achieving 97.3% uptime, 89 genuine hazard preventions, and 67% incident rate reduction validates that continuous automated monitoring successfully identifies dangers before injuries occur, contradicting traditional assumptions that practical training safety requires constant direct human supervision impossible given student-instructor ratios and facility dispersal, instead demonstrating technology-augmented supervision model enabling broader coverage through sensor networks supplementing rather than replacing human oversight [11].

The 73% emergency response time reduction from 8.5 to 2.3 minutes represents substantial improvement potentially preventing injury escalation through faster medical intervention, with particular importance for time-critical conditions including severe bleeding, cardiac events, heat stroke, or toxic exposures where survival probability and outcome severity correlate directly with treatment speed [12]. The 67% overall incident rate reduction from 12.3 to 4.1 per 1,000 students, with 83% reduction in chemical exposures and 78% reduction in heat-related illnesses, provides compelling empirical evidence that proactive environmental monitoring prevents injuries rather than merely responding after occurrence [13].

The 1,300% increase in near-miss reporting from 0.2 to 2.8 per 1,000 students illustrates positive safety culture transformation where automated detection captures precursor events enabling preventive interventions, contrasting with traditional systems' reporting reluctance and creating opportunities for proactive risk mitigation preventing escalation to actual injuries [14]. However, stakeholder-identified implementation challenges including device comfort issues affecting 73% of students, privacy concerns expressed by 60% of students and instructors, sustainability requirements estimating 1.5 additional full-time safety staff positions, and instructor burden from device management consuming 15-20 minutes per session, highlight that technical capability alone proves insufficient for sustainable adoption without corresponding investments in user interface improvements, privacy governance frameworks, dedicated support personnel, and organizational change management [15].

The finding that privacy concerns emerge even in legitimate safety applications demonstrates persistent tension between protective monitoring and surveillance perceptions, requiring careful governance frameworks transparently limiting data usage to genuine emergency response excluding disciplinary enforcement or performance evaluation preventing trust erosion and user resistance [16]. The mixed student behavioral impacts—8 of 15 reporting increased safety awareness while 7 of 15 acknowledging reduced personal vigilance—underscore importance of safety culture development emphasizing technology as supplement augmenting rather than replacing personal responsibility, avoiding technology dependence where automated monitoring inadvertently undermines individual situational awareness and hazard recognition skills essential for professional seafaring careers [17].

### 4. Conclusion

This research successfully designed, implemented, and validated Internet of Things occupational health and safety systems achieving 67% reduction in recordable incident rates from 12.3 to 4.1 per 1,000 students, 73% faster emergency response from 8.5 to 2.3 minutes through automated detection and dispatch, and 89 genuine hazard preventions protecting students during practical maritime training activities. Comprehensive stakeholder validation across safety officers, training instructors, and students revealed strong endorsement of proactive monitoring benefits including chemical exposure prevention, heat stress detection, confined space protection, and emergency response acceleration, though identifying critical implementation requirements including device comfort improvements addressing physical wearability concerns, privacy governance frameworks limiting data usage to legitimate safety purposes, dedicated support personnel managing sensor calibration and device logistics estimated at 1.5 additional full-time positions, and safety culture development emphasizing technology as supplement to rather than replacement for personal responsibility. The IoT platform deploying 423 sensors and wearable devices successfully monitored 47,500 student training hours across diverse hazardous activities, contributing validated architectures and empirical evidence supporting intelligent occupational health and safety management. The demonstrated incident reduction combined with regulatory compliance improvements increasing inspection scores from 76% to 94% positions IoT monitoring as genuine student welfare enhancement addressing Indonesia's maritime education safety imperatives while supporting institutional liability risk mitigation and quality assurance objectives critical to sustainable training operations protecting the 180,000-student maritime education population across national academy network.

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