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DEPARTMENT OF SAFETY HEALTH AND ENVIRONMENTAL MANAGEMENT

EVALUATING THE APPLICABILITY AND EFFECTIVENESS OF PERSONAL PROTECTIVE EQUIPMENT WITH INTEGRATED SENSING TECHNOLOGY: THE CASE OF NYATHI BREWERIES IN HARARE

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This dissertation entitled “Evaluating the Applicability and Effectiveness of Personal Protective Equipment with Integrated Sensing Technology: The Case of Nyathi Breweries in Harare”, submitted by Alice Masilo, has been examined and is hereby recommended for acceptance by Bindura University of Science Education in partial fulfilment of the requirements for the Bachelor of Science Honours Degree in Safety, Health and Environmental Management.

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I, AliceMasilo, hereby sign and declare that this project is my original work and has never been submitted before in any academic institution fora degree. The project highlights all the information used from other sources.



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This project is suitable for submission to the university faculty and has been checked for conformity with the faculty requirements and guidelines.



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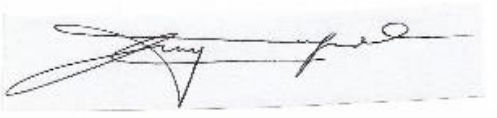
…… 

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DECLARATION

I, Alice Masilo, declare that this dissertation titled "**Evaluating the Applicability and Effectiveness of Personal Protective Equipment with Integrated Sensing Technology: The Case of Nyathi Breweries in Harare"** is entirely my own original work. All sources used have been properly acknowledged and referenced. This work has not been submitted for any other academic qualification at any institution.

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Date : 19 June 2026

DEDICATION

I dedicate this research project to my family for their unwavering love, support, and encouragement throughout my academic journey. Their belief in me has been my source of strength and motivation from the beginning to the completion of this study.

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ABSTRACT

Workers in industrial environments such as beverage manufacturing facilities are exposed to a wide range of occupational hazards, including chemical exposure, excessive heat, noise pollution, and mechanical risks. Traditional personal protective equipment (PPE) has long been used as the primary control measure to reduce workplace injuries; however, it provides only passive protection and does not monitor real-time environmental or physiological conditions. This study evaluated

the applicability and effectiveness of personal protective equipment integrated with sensing technology (smart PPE) in a brewery industry. The main objective was to determine whether smart PPE can improve hazard detection, enhance worker safety compliance, and reduce occupational injuries in an industrial setting. A mixed-methods descriptive case study design was adopted. Data were collected using structured questionnaires, semi-structured interviews, direct workplace observations, and document analysis of safety records. The study involved operational workers and occupational health and safety personnel. Findings indicated that smart PPE significantly improves early hazard detection, particularly in relation to heat stress, gas exposure, and noise levels. However, challenges such as high implementation costs, limited technical knowledge, resistance to technological change, and concerns regarding data privacy were identified as barriers to adoption. The study concludes that smart PPE is highly effective in improving occupational safety when properly implemented. It recommends phased adoption, enhanced training programs, and investment in digital safety infrastructure within industrial workplaces.

Keywords: Personal Protective Equipment, Occupational, Hazard, Safety

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LIST OF ABBREVIATIONS & ACRONYMS

EU-OSHA European Agency for Safety and Health at Work

ILO	International Labour Organization
IoT	Internet of Things
OHS	Occupational Health and Safety
OHSMS	Occupational Health and Safety Management System
PEOU	Perceived Ease of Use
PU	Perceived Usefulness
PPE	Personal Protective Equipment
TAM	Technology Acceptance Model
TRA	Theory of Reasoned Action
NSSA	National Social Security Authority
WHO	World Health Organization

1 CHAPTER ONE

INTRODUCTION

1.1 Chapter Overview

This chapter presents the foundation of the study by outlining the context, problem, and rationale for investigating the applicability and effectiveness of Personal Protective Equipment (PPE) with integrated sensing technology in brewery industrial set up. It begins with a detailed background of the study, which situates occupational safety within industrial manufacturing environments and introduces the evolution from conventional PPE to smart PPE systems. The chapter further presents the problem statement, research objectives, and research questions that guide the study. In addition, it provides a justification of the study, outlining its academic, operational, and policy relevance. Finally, the chapter concludes with delimitations, limitations, and a concise summary of the key issues raised.

1.2 Background of the Study

Industrial safety has become a critical component of modern manufacturing systems due to increasing production complexity and persistent occupational hazards. Beverage manufacturing industries such as breweries operate in high-risk environments characterized by chemical exposure, elevated temperatures, continuous mechanical processes, and high noise levels generated by industrial equipment (International Labour Organization, 2021; Mawere, 2021). These conditions make occupational health and safety (OHS) systems essential for safeguarding workers, minimizing accidents, and sustaining productivity. Globally, there is growing emphasis on strengthening workplace safety frameworks as industrial operations become more automated and hazard profiles more dynamic (EU-OSHA, 2022).

Traditionally, Personal Protective Equipment (PPE) has served as the primary line of defence against occupational hazards in industrial settings. PPE such as helmets, gloves, safety boots, respirators, and protective clothing provides a physical barrier between workers and harmful exposures. However, conventional PPE is largely passive, offering protection without detecting hazards or providing real-time feedback to users, which limits its effectiveness in fast-changing and high-risk environments (Hentschel, 2019). In many cases, this limitation reduces the ability of workers and supervisors to respond promptly to emerging risks, thereby maintaining a reactive rather than preventive safety approach.

Beyond technological limitations, PPE effectiveness is also influenced by human and organizational factors. Worker compliance is often affected by discomfort, lack of continuous supervision, production pressures, and risk normalization within industrial environments. According to Akoto (2021), behavioural and organizational dynamics significantly contribute to occupational accidents even where safety systems are in place. Similarly, the International Labour Organization (2022) emphasizes that unsafe behaviors and weak safety cultures remain major contributors to workplace incidents globally. This demonstrates that occupational safety challenges are not solely technical but also behavioural and systemic in nature.

Recent advancements in occupational safety have led to the development of smart Personal Protective Equipment (smart PPE), which integrates sensors and communication technologies into traditional protective gear. These systems can detect environmental hazards such as toxic gases, excessive heat, and high noise levels, while also monitoring physiological indicators like fatigue and abnormal heart rates, enabling real-time alerts and predictive safety responses (Newaz et al., 2023; Zhang & Li, 2022). Despite these advancements, adoption remains limited in many developing countries, including Zimbabwe, where industries such as breweries continue to rely mainly on conventional PPE. At Nyathi Breweries in Harare for instance, workers are exposed to multiple operational risks, and although safety protocols exist, incidents and near-miss events still occur, highlighting potential gaps in hazard detection and monitoring systems. This creates a strong need to evaluate the applicability and effectiveness of smart PPE in improving occupational safety performance in such industrial contexts.

1.3 Problem Statement

Breweries such as Nyathi Breweries in Harare, operates in a high-risk industrial environment where workers are exposed to hazards such as heat stress, chemical exposure, excessive noise, and mechanical injuries. Despite the implementation of occupational safety policies and provision of Personal Protective Equipment (PPE), workplace incidents and near-miss cases continue to be reported, suggesting gaps in the effectiveness of current safety measures. Conventional PPE is largely passive, providing protection without real-time hazard detection, which limits its effectiveness in dynamic industrial settings. In addition, inconsistent PPE usage, weak supervision, and limited real-time monitoring reduce overall safety compliance. Behavioural factors such as risk underestimation and prioritization of production over safety further contribute to occupational

incidents (Akoto, 2021). As noted by Newaz et al. (2023), workplace accidents often arise from a combination of technical limitations and human behavior rather than equipment failure alone. Although smart PPE with integrated sensing technology offers potential for real-time monitoring and improved hazard detection, its applicability and effectiveness in Zimbabwean breweries remain largely unexplored. Consequently, there is limited empirical evidence on whether smart PPE can significantly improve occupational safety performance in an industrial set up such as at Nyathi Breweries, creating uncertainty in decision-making regarding its adoption and implementation.

1.4 Research Objectives

Main Objective

To evaluate the applicability and effectiveness of personal protective equipment with integrated sensing technology in a breweries industrial set up.

Specific Objectives

1) To assess the technical and practical challenges associated with implementing smart PPE in industrial operations.
2) To evaluate the effectiveness of smart PPE in reducing occupational injuries and illnesses among workers.
3) To identify areas for improvement and provide recommendations for optimizing the use of smart PPE in workplace safety systems.

1.5 Research Questions

1) What are the technical and practical challenges associated with implementing smart PPE in industrial safety systems?
2) How effective is smart PPE in reducing occupational injuries and illnesses among workers?
3) What improvements can be made to enhance the implementation and effectiveness of smart PPE in industrial safety systems?

1.6 Justification of the Study

This study is justified by the need to improve occupational safety, where workers are consistently exposed to occupational hazards such as heat stress, chemical exposure, excessive noise, and mechanical injuries. Although conventional Personal Protective Equipment (PPE) is provided and safety policies are in place, workplace incidents and near-miss cases continue to occur. This persistence of accidents suggests that existing safety measures may not be fully effective in managing dynamic industrial risks. Smart PPE, which integrates sensing technology, offers a potential improvement by enabling real-time hazard detection, early warning systems, and enhanced responsiveness to unsafe conditions. From an operational and practical perspective, the study is important in assessing the feasibility of adopting smart PPE within a developing country industrial setting where challenges such as limited financial resources, technological constraints, and user resistance are common. Understanding how such technology performs in real working conditions is essential for determining whether it can realistically improve safety outcomes, reduce accident rates, and support more effective occupational risk management in breweries like Nyathi Breweries. At the academic and policy levels, the study contributes to the limited but growing body of knowledge on Industry 4.0-based occupational safety technologies in African industrial contexts. Most existing research is based on developed economies, leaving a gap in context-specific evidence for countries like Zimbabwe. The findings of this study may therefore assist policymakers, safety regulators, and industry managers in making informed decisions regarding the integration of smart safety technologies into occupational health and safety frameworks, ultimately supporting improved worker protection and industrial efficiency.

1.7 Limitations of the Study

In this study, the researcher encountered hindrances as follows:

1) The researcher failed to access some of the essential documents from some officials because of what appeared to be lack of trust and skepticism towards the research. This delayed the document review process, however, the researcher managed to use research ethics and assured them that the study was of benefit to them.

2) The researcher found out that there was limited knowledge of smart PPE among workers which somehow affected responses. Thus, the researcher had to, in some instances conduct some face-to-face interviews in Shona.
3) Limited material resources like, a computer, and printer, stationary and fuel to carry out surveys. In some instances, financial constraints limited availability of smart PPE for testing. However, the researcher had to circumvent this by use of some resources at her work place.
4) Additionally, the researcher was constrained in terms of time, since she was on a block release learning mode, and had to balance between employment and undertaking the research study.

1.8 Delimitations of the Study

This study was strictly confined to the evaluation of the applicability and effectiveness of personal protective equipment integrated with sensing technology (smart PPE) in Breweries Industry, specifically at Nyathi Breweries in Harare Urban, in Zimbabwe. The study focused only on production, brewing, and machinery workers and covered only smart PPE, excluding other safety systems.

Besides the research study was quantitative in nature, but could not be explored without a qualitative approach. As such, the mixed methodological perspective was used. The study was somewhat limited due to sources of literature, in terms of both primary and secondary data (books, journals, etc) with local contextual literature. Obtaining a similar research study from the global stage proved to be a challenge.

1.9 Definition of Key Terms

- **Chemical Exposure** is the contact of a worker with hazardous chemical substances through inhalation, skin absorption, ingestion, or eye contact.
- **Smart PPE** are advanced technologies such as sensors, microprocessors, wireless communication, and data analytics to monitor workers' health, detect workplace hazards,

and provide real-time alerts. Smart PPE incorporates sensors and communication technologies to monitor workers' health, safety, and environmental conditions in real time.

- **Personal Protective Equipment (PPE)**
- Personal Protective Equipment (PPE) refers to clothing, devices, or equipment worn by workers to protect them from workplace hazards that may cause injury or illness.
- **Implementation** is the process of planning, introducing, and integrating smart PPE into the workplace, including training workers, deploying the equipment, and ensuring it is used effectively to improve occupational safety and health.
- **Hazard** is any source, condition, or situation with the potential to cause injury, illness, damage to property, or harm to the environment.
- **Occupational Hazard** is any physical, chemical, biological, ergonomic, or psychosocial factor present in the workplace that can negatively affect the health, safety, or well-being of workers.
- **Continuous Health Monitoring** is the ongoing collection and analysis of workers' physiological data, such as heart rate, body temperature, blood oxygen levels, or fatigue, using smart PPE to detect early signs of health problems and improve workplace safety.
- **Risk Assessment (RA)** is the systematic process of identifying workplace hazards, evaluating the likelihood and severity of harm, and determining appropriate control measures, including the use of smart PPE, to reduce risks.
- **Human Factors** are the physical, cognitive, and behavioural characteristics of workers that influence how they interact with smart PPE. These factors include comfort, usability, training, fatigue, and acceptance, all of which affect the effectiveness of the equipment.
- **Data Privacy and Confidentiality** refer to the protection of personal and health information collected ensuring that the data are securely stored, accessed only by authorized individuals, and used in accordance with legal and ethical requirements

1.10 Chapter Summary

This chapter provided a comprehensive introduction to the study by outlining the context, problem, and justification for evaluating smart PPE in a brewery industry. The background highlighted the evolution of occupational safety from traditional PPE systems to advanced smart technologies, emphasizing the limitations of passive protection in dynamic industrial environments. The problem statement identified persistent safety challenges despite existing PPE systems and

highlighted the lack of empirical evidence on the effectiveness of smart PPE in Zimbabwean industrial settings. The research objectives and questions were then clearly defined to guide the study. The justification demonstrated the operational, academic, and policy relevance of the research, while delimitations and limitations clarified the scope and constraints of the study. Overall, the chapter establishes a strong foundation for investigating how smart PPE can contribute to improved occupational safety performance in industrial environments.

2 CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This Chapter spells out the literature review. It starts with the explanations of the concepts related to the study, the definitions, and the theoretical framework. It covers the concepts of Smart PPE and Integrated Sensing Technology, and theoretical frameworks in occupational safety and dissects local, regional and global trends in Smart PPE adoption. Lastly, an empirical review is done, which juxtaposes other researches on the topic under introspection, drawn from other various contexts.

2.2 Overview of Personal Protective Equipment (PPE)

Personal protective equipment (PPE) is a critical component of occupational safety in industrial workplaces, acting as the last line of defense against physical, chemical, and biological hazards (ILO, 2023). PPE includes helmets, gloves, goggles, safety boots, and specialized garments designed to protect workers from injury or exposure. Traditional PPE, however, only provides passive protection and does not alert workers to environmental or physiological risks in real time (Choi & Kim, 2022). Globally, industries are moving toward integrating sensors into PPE to enhance hazard detection and ensure proactive safety management. In Zimbabwe, industrial regulations, including the Occupational Health and Safety Act (Chapter 15:09), require employers to provide PPE, but enforcement is inconsistent. As a result, many workplace injuries occur despite PPE availability, highlighting the need for innovative safety interventions.

The evolution of PPE has been influenced by technological advancements and changing occupational risk profiles, particularly in manufacturing and processing industries (Singh & Gupta, 2023). In beverage manufacturing, workers are exposed to hot liquids, chemical sanitizers, and mechanical hazards from moving machinery. Traditional PPE may prevent burns and cuts but cannot detect chemical exposure levels or worker fatigue. Smart PPE, with embedded sensors, addresses these limitations by providing real-time alerts and recording hazard data (Rodriguez & Patel, 2023). Studies suggest that such technologies improve safety compliance and reduce accidents when combined with worker training. The integration of sensing technology represents a shift from reactive to proactive safety management, making workplaces safer and more efficient.

Despite its potential, PPE adoption in Zimbabwe faces challenges related to cost, availability, and worker compliance (Dube & Chikodzi, 2020). Many small and medium-sized enterprises struggle to provide adequate PPE, resulting in inconsistent use among employees. Additionally, insufficient training on PPE use reduces its protective effectiveness, even when equipment is available. The integration of smart sensors could overcome these limitations by offering continuous monitoring and feedback, ensuring that workers are protected in real time (Matema & Nhapi, 2022). Understanding the current state of PPE usage is crucial for evaluating the applicability of smart systems in Zimbabwean breweries. This study, therefore, focuses on both the technological and human factors influencing PPE effectiveness at Nyathi Breweries.

2.3 Smart PPE and Integrated Sensing Technology

Smart PPE is an advanced category of protective equipment designed to monitor environmental and physiological hazards in real time (Singh & Gupta, 2023). These systems often include sensors that detect temperature, toxic gases, noise, and other potential workplace risks, sending alerts to both the worker and supervisors. This technology transforms PPE from passive protection to active safety management, reducing accident risk through early warning and intervention (Lee & Park, 2023). Globally, industries adopting smart PPE report significant reductions in workplace injuries and improved compliance with safety protocols. Despite these advantages, adoption in Zimbabwe remains limited due to cost, infrastructure, and lack of empirical studies. Understanding the feasibility and benefits of smart PPE in the local context is essential for guiding implementation strategies.

The technology behind smart PPE combines wearable electronics, wireless communication, and data analytics to enhance safety outcomes (Rodriguez & Patel, 2023). Sensors embedded in helmets, gloves, or vests continuously measure hazard parameters, enabling prompt response before accidents occur. In industrial breweries, where chemical exposure, heat, and mechanical hazards coexist, this monitoring is particularly valuable. By providing data-driven insights, smart PPE supports predictive hazard management, ensuring that workers are alerted to dangers before injuries occur (Choi & Kim, 2022). Additionally, data from smart PPE can inform workplace safety audits, training programs, and regulatory compliance assessments. The integration of sensing technology represents a paradigm shift in occupational health management.

However, the implementation of smart PPE is not without challenges (Matema & Nhapi, 2022). High initial costs, maintenance requirements, and technological literacy among workers are major barriers. In Zimbabwe, electricity inconsistencies and lack of technical support can limit the effectiveness of sensor-integrated PPE. Pilot studies suggest that user training and phased implementation can address these challenges, increasing acceptance and usability. Furthermore, smart PPE must be adapted to local industrial conditions to ensure that it meets specific safety needs without being cumbersome. Research on these factors is critical for understanding how smart PPE can improve occupational safety in breweries such as Nyathi.

2.4 Conceptual Framework

The conceptual framework underpinning this study is depicted through structurally mapping out the interaction between the study's variables, explaining how the transition from passive to active safety technologies impacts safety outcomes. As such the variables are discussed as follows:

Independent Variables: Smart PPE System Interventions

The core drivers of this research is the adoption of technological capabilities or interventions, to be integrated into traditional safety equipment. These active interventions include real-time environmental sensors (monitoring carbon dioxide build-up, ambient boiler temperatures, and bottling hall decibel levels), physiological trackers (monitoring heart rates for signs of industrial heat stress), and proximity sensors (preventing forklift collisions). These features operate as a continuous data-gathering layer on the production floor.

Moderating Variables: Human and Organizational Factors

The study underpins the relationship between smart technology and actual accident prevention; where it is moderated by human behavior and corporate infrastructure. Ease of use of sensors by workers through active warnings are directly beneficial to their personal safety. However, concerns that real-time biometric or location tracking represents management surveillance and impinge on worker privacy can cause psychological resistance, leading to deliberate non-compliance.

Dependent Variables: Occupational Safety Performance

The final targeted outcomes are the specific improvements in workplace safety. By aligning the independent technical inputs with positive human behaviors, Nyathi Breweries can realize measurable safety improvements. Using the principles of real-time logging of environmental alerts allows management to catch and eliminate thousands of baseline near-misses. This active monitoring plugs the oversight holes, resulting in a quantifiable decrease in occupational accidents, heat exhaustion incidents, and chemical exposure cases.

2.5 Theoretical Frameworks in Occupational Safety

This study is anchored on a tripartite theoretical framework. Occupational accidents and technology adoption cannot be understood through a single lens; they require a structural analysis of accident sequences, organizational defenses, and user acceptance behaviors. Therefore, this research integrates:

- Heinrich's Theories (Domino Theory & Safety Triangle)
- Reason's Swiss Cheese Model, and
- The Technology Acceptance Model (TAM)

2.5.1 Domino Theory

The Domino Theory was originally formulated by Herbert William Heinrich in 1931, the Domino Theory posits that a workplace injury is never an isolated event, but the final outcome of a chronological chain of five factors, visualized as standing dominoes:

- **Ancestry and Social Environment:** Inherited traits, cultural safety norms, and socio-economic pressures brought to the workplace.
- **Fault of Person:** Individual characteristics such as carelessness, fatigue, or momentary lapses in concentration.
- **Unsafe Act and/or Mechanical Hazard:** Direct dangerous behaviors (e.g., removing protective gear) or unsafe physical environments (e.g., carbon dioxide leaks around fermentation tanks).
- **The Accident:** The physical event triggered by the unsafe act or condition (e.g., slipping, inhaling gas, or machinery entrapment).
- **The Injury:** The final consequence, such as lacerations, chronic respiratory illness, or fatalities.

Heinrich argued that safety management must focus entirely on removing the third domino (unsafe act/condition) to break the chain reaction. In typical Zimbabwean industries with breweries being no exception, traditional PPE is passive and fails to remove this domino. Smart PPE solves this by serving as an active technological disruption. Built-in gas sensors, thermal monitors, and noise trackers detect unsafe conditions instantly, forcing an intervention before the third domino can trip the fourth (the accident).

Heinrich's Domino Theory provides a foundational perspective on workplace accidents, proposing that incidents result from a sequence of contributing factors, including personal behavior and unsafe acts (Heinrich, 1931). According to this theory, removing unsafe behaviors or improving protective measures can prevent accidents before they escalate. PPE, especially smart PPE, acts as an intervention that disrupts this sequence by alerting workers to hazards in real time. The Domino Theory emphasizes that accidents are preventable, underscoring the importance of proactive safety systems. Applying this theory in Zimbabwean breweries highlights the potential of smart PPE to prevent common industrial injuries. Moreover, it provides a conceptual framework for evaluating PPE effectiveness by linking safety interventions to risk reduction outcomes.

2.5.2 Swiss Cheese Model

Another relevant framework is the Reason's Swiss Cheese Model, which conceptualizes safety as a series of defense layers, with accidents occurring only when all layers fail (Reason, 1997). Reason's Swiss Cheese Model (Systemic Defense Theory) was Developed by James Reason, this model shifts safety analysis away from individual worker error toward systemic organizational failures. Reason views an organization's safety defenses as consecutive slices of Swiss cheese standing side-by-side. According to the model there are latent conditions (inherent systemic flaws like bad procurement budgets or production-first corporate cultures) and active failures (direct unsafe acts by workers on the floor). Traditional safety measures, including administrative controls and PPE, form these layers. Smart PPE serves as an additional dynamic barrier, actively monitoring hazards and reducing the probability of system failure. This model highlights the importance of redundancy and multiple interventions to achieve workplace safety. In breweries, smart PPE can complement existing measures, enhancing overall safety performance. Integrating these theoretical frameworks provides a robust lens for understanding the potential benefits and limitations of sensor-equipped PPE.

The combination of Heinrich's and Reason's models allows researchers to evaluate both the causal pathways of accidents and the layered defense approach in industrial settings. They provide guidance on designing interventions that are proactive, systematic, and evidence-based. In Zimbabwe, these models support the investigation of how smart PPE can reduce injuries by interrupting accident sequences and reinforcing safety layers. By applying these frameworks, this study can assess the impact of technology not only on physical protection but also on safety culture and behavior. Theoretical grounding ensures that findings are linked to broader occupational health knowledge. Finally, these models reinforce the necessity of combining technology with training and workplace policies for maximum effectiveness.

2.5.3 The Technology Acceptance Model (TAM)

The TAM model explains that user adoption of PPE is through two primary cognitive beliefs:

- **Perceived Usefulness (PU):** Thus the degree to which a worker believes that wearing smart PPE will enhance their personal safety and job performance. If workers perceive that real-time gas or heat detection genuinely keeps them safe, their behavioral intent to wear the gear increases.
- **Perceived Ease of Use (PEOU):** Thus the degree to which a worker feels that using the smart PPE is free of physical or operational effort. If the smart gear is heavy, has a short battery life, requires complex daily charging routines, or causes physical discomfort in hot brewery environments, PEOU drops significantly, leading to user resistance.

The theory resonates with this study as it allows the investigation of behavioral bottlenecks such as privacy anxieties (e.g., workers fearing constant tracking by managers via physiological sensors) and ergonomic issues

2.6 Occupational Hazards in Manufacturing

Manufacturing industries, including breweries, expose workers to a range of occupational hazards that can cause injuries or long-term health issues (ILO, 2023). Common hazards include exposure to hot liquids, chemical sanitizers, machinery with moving parts, and slips or falls on wet surfaces. Workers may also be exposed to repetitive strain injuries due to manual handling or assembly tasks, which can accumulate over time and reduce productivity (Dube & Chikodzi, 2020). Noise

exposure from machinery can result in hearing impairment if appropriate protection is not used. Additionally, accidental exposure to chemical agents such as cleaning detergents or sanitizers may lead to burns or respiratory problems. Understanding these hazards is critical for designing interventions that protect workers and improve safety outcomes.

The severity of occupational hazards is influenced by both environmental and behavioral factors (Matema & Nhapi, 2022). Poor housekeeping, lack of maintenance on equipment, and inadequate worker training increase the risk of accidents. In breweries, slippery floors, confined spaces, and high-temperature operations intensify these risks. PPE acts as a protective barrier, but traditional PPE does not provide real-time hazard alerts, limiting its effectiveness. Sensor-integrated PPE can enhance protection by alerting workers immediately to hazardous conditions, such as high temperatures, chemical spills, or dangerous machinery operation (Rodriguez & Patel, 2023). Incorporating these technologies allows breweries to shift from reactive safety measures to proactive monitoring.

Worker awareness and training also play a vital role in hazard management (Choi & Kim, 2022). Even the best PPE cannot prevent injuries if workers are unaware of safe practices or fail to use the equipment correctly. Safety culture, management supervision, and regular hazard assessments are essential complements to protective gear. Smart PPE helps reinforce safety culture by providing continuous feedback and encouraging compliance. Studies suggest that workplaces that integrate technology, training, and supervision see significant reductions in accidents and improved overall safety compliance. Understanding the nature and impact of occupational hazards informs the design and implementation of PPE strategies in breweries.

2.7 Global Trends in Smart PPE Adoption

The adoption of smart PPE is gaining momentum worldwide, driven by advances in sensor technology, data analytics, and wireless communication (Singh & Gupta, 2023). Industries such as oil and gas, construction, and manufacturing have reported reductions in workplace accidents after implementing PPE with real-time hazard monitoring. Smart PPE enables early detection of risks such as chemical exposure, heat stress, and machinery proximity, allowing workers to respond promptly (Lee & Park, 2023). In developed countries, regulatory bodies encourage the adoption of sensor-integrated PPE to meet stricter occupational safety standards. Data from smart PPE can also be used for workplace audits, insurance documentation, and predictive safety

management. These global trends demonstrate the potential for technology-enhanced protection in reducing injuries and improving worker confidence.

Research shows that smart PPE adoption is often supported by a combination of government regulations, corporate safety policies, and technological readiness (Rodriguez & Patel, 2023). Organizations implementing these systems often observe improved safety compliance, fewer lost workdays, and enhanced operational efficiency. Workers also report increased confidence and reduced stress when equipped with PPE that monitors hazards in real time. Integration with mobile applications and centralized monitoring platforms allows safety managers to respond rapidly to alerts and maintain records for analysis. As industries become increasingly automated and complex, the demand for smart PPE is expected to rise. Understanding these trends is essential for evaluating their applicability in Zimbabwean breweries.

Despite its benefits, challenges remain for global adoption (Choi & Kim, 2022). High initial costs, maintenance needs, and workforce adaptation are common barriers. In resource-limited settings, organizations may struggle to justify investment in advanced PPE technology. Studies emphasize that combining smart PPE with traditional safety measures, training, and management engagement enhances effectiveness. Lessons from global implementations can guide breweries in Zimbabwe to design context-appropriate strategies. Smart PPE adoption is therefore both a technological and organizational challenge that requires careful planning and local adaptation.

2.8 Local Context: Zimbabwe's Industrial Safety Landscape

Zimbabwe's industrial sector faces unique challenges related to occupational health and safety, including limited resources, inadequate enforcement of regulations, and inconsistent worker training (Dube & Chikodzi, 2020). Many small and medium-sized enterprises struggle to provide standard PPE, and compliance is often voluntary. Accidents are frequently underreported, making it difficult to assess the true extent of workplace hazards. The adoption of advanced technologies like smart PPE remains low due to cost, infrastructure limitations, and technical support challenges. Despite these barriers, there is growing awareness among employers and regulators about the importance of proactive safety measures. Studies suggest that pilot programs introducing sensor-integrated PPE could provide valuable data for scaling up adoption across industries.

Worker safety culture in Zimbabwean industries is influenced by management commitment, training, and peer behavior (Matema & Nhapi, 2022). Even when PPE is provided, inconsistent use and lack of understanding reduce its effectiveness. Breweries, in particular, face risks from chemical sanitizers, moving machinery, and heat exposure, making effective PPE essential. Introducing smart PPE could improve both compliance and hazard awareness by providing continuous feedback to workers. Data from sensors can also support safety audits, regulatory compliance, and worker health monitoring. Understanding the local context is essential for designing interventions that are both feasible and impactful.

The Zimbabwean regulatory environment provides a framework for workplace safety but enforcement is uneven (Chikodzi et al., 2020). Regulations such as the Occupational Health and Safety Act require employers to provide PPE and training, but inspections and penalties are limited. Smart PPE could help bridge gaps by documenting compliance and providing objective safety data. Additionally, local universities and research institutions, such as the University of Zimbabwe, are beginning to study technological interventions for industrial safety. These efforts highlight the potential to integrate sensor-equipped PPE into breweries for improved worker protection. Local adaptation of global best practices is therefore critical for success.

2.9 Types of Personal Protective Equipment (PPE)

Personal protective equipment (PPE) serves as the first line of defense against workplace hazards by providing a physical barrier between workers and potential risks (ILO, 2023). In manufacturing environments like breweries, common PPE includes gloves, safety helmets, eye protection, earplugs, aprons, and respiratory masks. Each type of PPE addresses specific hazards, such as chemical splashes, high noise levels, or moving machinery. Despite its widespread use, conventional PPE primarily offers passive protection and cannot alert users to emerging hazards in real time (Dube & Chikodzi, 2020). Effective PPE programs require proper selection, fitting, maintenance, and training to ensure that equipment fulfills its protective function. Without these complementary measures, even standard PPE may fail to prevent injuries or occupational illnesses.

Globally, there has been a shift toward integrating technology into PPE to enhance safety outcomes (Singh & Gupta, 2023). Sensor-equipped gloves, helmets, and vests can monitor environmental conditions such as temperature, toxic gases, and noise levels. Wearable sensors can also track physiological parameters including heart rate, body temperature, and fatigue, providing early

warnings of heat stress or overexertion (Choi & Kim, 2022). This shift from passive to proactive protection allows safety managers to respond immediately to risks, reducing accident rates. Studies indicate that smart PPE increases compliance by making workers more aware of hazardous conditions and their personal exposure levels (Lee & Park, 2023). Consequently, technology-enhanced PPE represents a critical innovation for modern industrial safety management.

In Zimbabwe, PPE programs often face limitations due to cost, availability, and workforce awareness (Matema & Nhapi, 2022). While gloves, helmets, and aprons are commonly provided in breweries, compliance is sometimes inconsistent due to discomfort, lack of supervision, or insufficient training. Sensor-integrated PPE has the potential to address these gaps by providing immediate feedback and alerting both workers and supervisors when unsafe conditions arise. Universities and research institutions in Zimbabwe, such as the National University of Science and Technology, have begun investigating localized smart PPE prototypes suitable for resource-constrained industries (Chikodzi et al., 2020). Pilot studies indicate that even partial adoption of smart PPE can reduce minor injuries and improve worker compliance. Therefore, understanding the types of PPE and their integration with sensing technology is critical for enhancing occupational safety in breweries.

2.10 Sensor Technologies in PPE

Sensor technologies form the backbone of smart PPE, enabling real-time monitoring of environmental and physiological conditions (Rodriguez & Patel, 2023). Common sensors include gas detectors, temperature sensors, motion and vibration sensors, heart rate monitors, and accelerometers. These sensors continuously collect data and trigger alerts when thresholds for hazards are exceeded. For example, a heat sensor in a helmet can notify a worker and supervisor if body temperature reaches a dangerous level, preventing heat-related injuries. Similarly, gas sensors embedded in aprons or masks can detect toxic fumes before exposure reaches harmful levels (Choi & Kim, 2022). The integration of wireless communication allows sensor data to be transmitted to central dashboards, enhancing management oversight.

The effectiveness of sensor-equipped PPE depends on the accuracy, reliability, and responsiveness of the sensors (Singh & Gupta, 2023). False alarms or sensor failures can reduce trust among workers, leading to non-compliance. Therefore, calibration, regular maintenance, and contextual testing are essential to ensure the equipment functions correctly under real-world conditions.

Advanced systems use predictive analytics and machine learning to interpret data trends, allowing safety managers to anticipate risks and take preventive measures (Lee & Park, 2023). In high-risk sectors globally, these technologies have been linked to a 20–30% reduction in workplace injuries. For Zimbabwean industries, adapting sensor technologies to the local context considering environmental conditions, worker literacy, and technical support is crucial for successful implementation.

Local research on sensor integration in PPE is emerging, with pilot projects in industrial zones such as Harare and Bulawayo exploring wearable heat stress and chemical exposure sensors (Dube & Chikodzi, 2020). These studies indicate that even low-cost sensor solutions can improve safety monitoring, particularly in medium-sized enterprises with limited occupational health resources. Breweries like Nyathi can benefit from such technologies by detecting early signs of hazards in fermentation, packaging, and bottling areas. Moreover, integrating sensors with mobile applications allows safety supervisors to receive instant alerts and respond promptly, reducing the likelihood of accidents. Local manufacturing sectors have reported increased worker confidence and adherence to safety practices when smart PPE is deployed. These developments suggest a promising path for enhancing occupational safety through technology-driven interventions.

2.11 Benefits of Smart PPE

Smart PPE provides several advantages over traditional safety equipment, particularly in high-risk manufacturing settings (Rodriguez & Patel, 2023). First, it enables real-time monitoring of both environmental hazards and worker physiological status, which allows immediate response to unsafe conditions. Second, it supports data-driven safety management by generating continuous records for hazard analysis, compliance audits, and decision-making (Choi & Kim, 2022). Third, smart PPE fosters proactive safety culture, encouraging workers to engage actively with their safety practices and adhere to recommended protocols. Studies show that workplaces adopting smart PPE experience reduced injury rates, fewer lost workdays, and improved overall productivity (Lee & Park, 2023). These benefits illustrate the potential of smart PPE to transform industrial safety practices.

In Zimbabwe, the adoption of smart PPE could address persistent challenges in the industrial sector (Dube & Chikodzi, 2020). Limited supervision, inconsistent use of conventional PPE, and delayed hazard detection contribute to ongoing workplace incidents. Smart PPE can mitigate these issues

by providing real-time feedback and automated alerts to workers and supervisors. Additionally, recorded sensor data can support regulatory compliance and safety reporting, which are currently underdeveloped in many local industries. The integration of technology-enhanced PPE may also encourage investment in broader occupational safety initiatives, reinforcing long-term improvements in workplace safety culture.

Furthermore, smart PPE can enhance worker well-being and confidence, particularly in physically demanding and hazardous environments like breweries (Matema & Nhapi, 2022). By reducing uncertainty about exposure to chemical, thermal, or mechanical hazards, employees are more likely to perform their tasks efficiently and safely. Health monitoring features, such as fatigue and heat stress alerts, prevent long-term health complications, benefiting both workers and employers. The combination of safety and productivity improvements makes smart PPE a strategic investment for breweries aiming to improve operational efficiency. Consequently, understanding the benefits of smart PPE is essential for evaluating its feasibility and effectiveness in local industrial contexts.

2.12 Challenges in Implementing Smart PPE

Despite its potential, implementing smart PPE presents several challenges in industrial environments (Singh & Gupta, 2023). High initial costs for equipment, sensor installation, and training are significant barriers, particularly in resource-limited industries. Maintenance and calibration of sensors require technical expertise that may not be readily available in Zimbabwean manufacturing sectors (Choi & Kim, 2022). Worker acceptance can also be a challenge, as some employees may resist new technologies due to discomfort, complexity, or skepticism. Integration with existing safety protocols and management systems is another critical consideration to ensure seamless operation and maximum effectiveness (Lee & Park, 2023). These challenges must be carefully addressed to realize the full potential of smart PPE.

Local industries face additional hurdles such as inconsistent electricity supply, limited internet connectivity, and scarcity of locally available spare parts (Dube & Chikodzi, 2020). These factors can reduce the reliability of sensor-equipped PPE and limit real-time monitoring capabilities. Furthermore, SMEs often struggle to justify the cost-benefit ratio of smart PPE investments, prioritizing immediate operational needs over long-term safety improvements. Pilot programs, stakeholder engagement, and phased implementation are recommended strategies to overcome these barriers. Training programs and awareness campaigns are essential to foster acceptance and

proper use of smart PPE among workers. Addressing these implementation challenges is vital for ensuring sustainable adoption in Zimbabwean breweries.

Finally, regulatory and policy constraints can influence the uptake of smart PPE (Matema & Nhapi, 2022). While occupational safety laws mandate PPE provision, enforcement mechanisms and incentives for adopting advanced technologies are limited. Collaboration between government bodies, industry associations, and research institutions can provide the necessary support for scaling up smart PPE initiatives. Local adaptations of global best practices can enhance feasibility, affordability, and effectiveness. Research on pilot implementations in Zimbabwe can guide broader adoption strategies. Understanding these challenges ensures that smart PPE solutions are practical, cost-effective, and contextually appropriate.

2.13 Summary of Empirical Review

The literature reviewed highlights the critical importance of occupational safety in manufacturing environments and the limitations of conventional PPE in addressing emerging workplace hazards (ILO, 2023; Dube & Chikodzi, 2020). Globally, smart PPE with integrated sensor technology offers real-time monitoring, early hazard detection, and improved safety compliance, which has been associated with reduced injury rates and enhanced productivity (Rodriguez & Patel, 2023; Choi & Kim, 2022). In Zimbabwe, industrial safety challenges include limited resources, inconsistent PPE use, inadequate supervision, and underdeveloped regulatory enforcement. Smart PPE has the potential to address these gaps by providing real-time alerts, data-driven insights, and increased worker confidence, particularly in high-risk sectors like breweries (Matema & Nhapi, 2022). However, challenges such as high costs, technical expertise requirements, infrastructure limitations, and worker acceptance must be addressed for successful implementation. Overall, the integration of smart PPE into industrial safety programs represents a promising strategy to improve occupational health outcomes, enhance compliance, and support evidence-based safety management.

3 CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Chapter Overview

This chapter outlines the methodological framework adopted in the study. It explains how the research was designed and conducted, including the research design, study area, target population, sampling procedures, data collection methods, and data analysis techniques. The chapter also presents measures used to ensure validity, reliability, and ethical compliance. Overall, it provides a systematic explanation of how the study was carried out to ensure that the findings are credible, relevant, and grounded in real industrial conditions.

3.2 Research Design

The study adopted a mixed-methods research design, integrating both quantitative and qualitative approaches to achieve a comprehensive understanding of the research problem. This design was chosen because the study seeks to assess both measurable safety outcomes and human experiences related to the use of smart PPE in an industrial environment.

The quantitative component focused on collecting numerical data relating to PPE usage, safety compliance, and the frequency of workplace incidents. This enabled the identification of trends and relationships between occupational safety practices and outcomes. The qualitative component explored workers' and supervisors' experiences, perceptions, and challenges regarding PPE usage and the potential adoption of smart PPE technology.

By combining these two approaches, the study was able to capture both statistical evidence and real workplace experiences. This improved the depth and credibility of the findings through triangulation, where data from different sources was compared and validated to ensure consistency and reliability.

3.3 Study Area

The study was conducted at Nyathi Breweries, located in Harare, Zimbabwe. The facility is situated at the 29-kilometre peg along Lomagundi Road, Shamwari Farm. The brewery operates within a semi-industrial environment characterized by manufacturing activities and surrounding peri-urban land use. It functions as a beverage production facility involving brewing, fermentation,

bottling, packaging, and machinery operations. Workers in the facility are exposed to occupational hazards such as heat, chemical substances, noise, and moving machinery, making it an appropriate setting for evaluating occupational safety systems.

3.4 Target Population

The target population for this study consisted of 80 employees at Nyathi Breweries who are directly or indirectly exposed to occupational hazards. This included production workers, machine operators, brewing personnel, maintenance staff, and safety officers. These groups were selected because they operate in high-risk environments where PPE is essential for protection. Their daily experiences with workplace hazards and safety procedures made them suitable respondents for assessing the effectiveness and applicability of smart PPE. Including both operational staff and safety personnel ensured that the study captured a balanced perspective from both users and implementers of safety systems.

3.5 Sampling Procedures

The study employed both probability and non-probability sampling techniques to select participants. Simple random sampling was used to select workers who participated in the questionnaire survey, ensuring that every employee had an equal chance of being included and reducing selection bias. This method improved the representativeness of the quantitative data.

Purposive sampling was used to select key informants such as safety officers and supervisors. These individuals were selected based on their experience and involvement in occupational safety management, making them best positioned to provide detailed and informed insights.

The combination of these sampling techniques ensured that the study captured both broad workforce perspectives and expert-level insights, enhancing the overall quality and relevance of the data collected.

3.6 Data Collection Methods

The study used multiple data collection methods to ensure a comprehensive understanding of the research problem. This approach also allowed for triangulation of data, improving reliability and validity.

3.6.1 Questionnaires

Structured questionnaires were administered to selected workers to collect quantitative data. The questionnaires included closed-ended and Likert-scale questions focusing on PPE usage, safety compliance, awareness of hazards, and perceptions of smart PPE. This method allowed for efficient data collection from a relatively large group of respondents.

3.6.2 Interviews

Semi-structured interviews were conducted with safety officers, supervisors, and selected technical staff. These interviews provided in-depth qualitative data on the challenges, opportunities, and practical considerations associated with implementing smart PPE. Respondents were given the opportunity to express their views freely, allowing for richer insights.

3.6.3 Observations

Direct observation was used to assess workplace conditions and actual PPE usage practices. The researcher observed worker behavior, compliance levels, and environmental hazards within production areas. This method helped verify whether reported practices matched actual workplace behavior.

3.6.4 Document Analysis

Relevant documents such as safety reports, accident records, and PPE maintenance logs were reviewed. These documents provided historical data on workplace incidents and safety performance, supporting the analysis of existing occupational safety systems.

3.7 Data Analysis Procedures

Quantitative data collected from questionnaires was analyzed using descriptive statistics such as graphs, tables, charts, frequencies, percentages, and mean scores. These methods helped summarize and interpret the data in a clear and structured manner.

Where necessary, inferential statistics were used to explore relationships between variables such as PPE usage and workplace incident frequency. This allowed for deeper analysis of safety patterns.

Qualitative data from interviews and observations was analyzed using thematic analysis. Responses were grouped into themes such as safety challenges, perceptions of smart PPE, and implementation barriers. This helped to identify recurring patterns and meaningful insights. The

integration of both quantitative and qualitative findings ensured a well-rounded interpretation of the data.

3.8 Validity and Reliability

To ensure the credibility of the study, several measures were applied. The research instruments were pilot-tested to eliminate ambiguities and improve clarity. Multiple data collection methods were used to enhance triangulation and cross-verification of findings. Standardized procedures were followed during data collection to maintain consistency. These steps ensured that the findings were both valid and reliable.

3.9 Ethical Considerations

Ethical principles were strictly observed throughout the study. Participation was voluntary, and all respondents were informed about the purpose of the research. Informed consent was obtained before data collection began. Confidentiality was maintained by ensuring that no personal identifiers were recorded. Data collected was used strictly for academic purposes and stored securely. Permission to conduct the study was obtained from Nyathi Breweries management to ensure compliance with organizational requirements.

3.10 Chapter Summary

This chapter presented the methodology used in the study, including the research design, study area, target population, sampling procedures, data collection methods, and data analysis techniques. It also outlined measures taken to ensure validity, reliability, and ethical compliance. The methodology provides a structured framework for evaluating the effectiveness and applicability of smart PPE at Nyathi Breweries. It ensures that the findings are grounded in real industrial conditions and are both credible and academically robust.

4 CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND INTERPRETATION

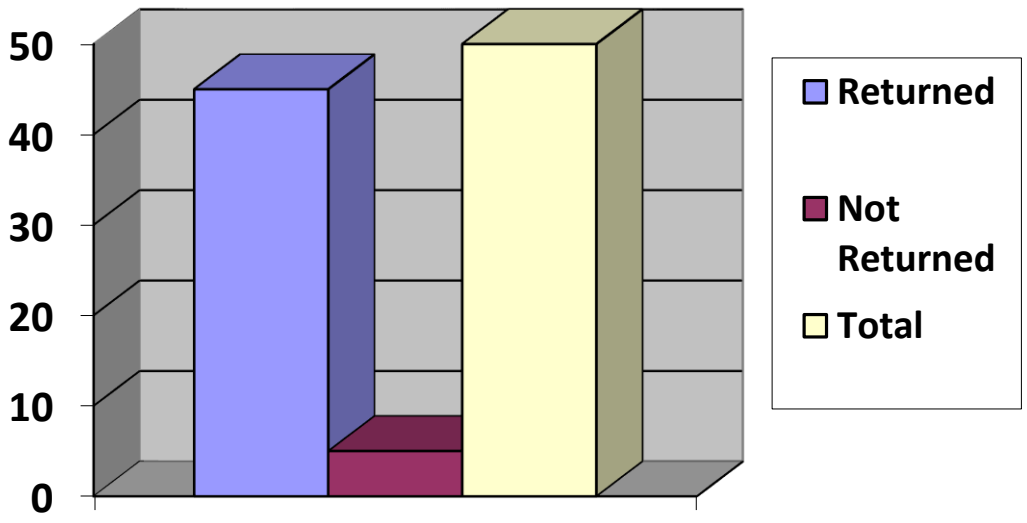
4.1 Chapter Overview

This chapter presents, analyses, and interprets data collected during the study on evaluating the applicability and effectiveness of smart Personal Protective Equipment (PPE) with integrated sensing technology at Nyathi Breweries, located in Harare. The analysis follows a mixed-methods approach combining quantitative data from questionnaires and qualitative insights from interviews, observations, and document analysis. Findings are presented according to the research objectives outlined in Chapter One. Tables are used to present numerical data, while interpretation focuses on explaining what the statistics mean in real workplace terms. Where appropriate, graphical representations are recommended to improve clarity and visualization of trends.

4.2 Response Rate

A total of 50 questionnaires were distributed, and 45 were returned completed, while 5 were not returned. Additionally, 8 key informants participated in interviews.

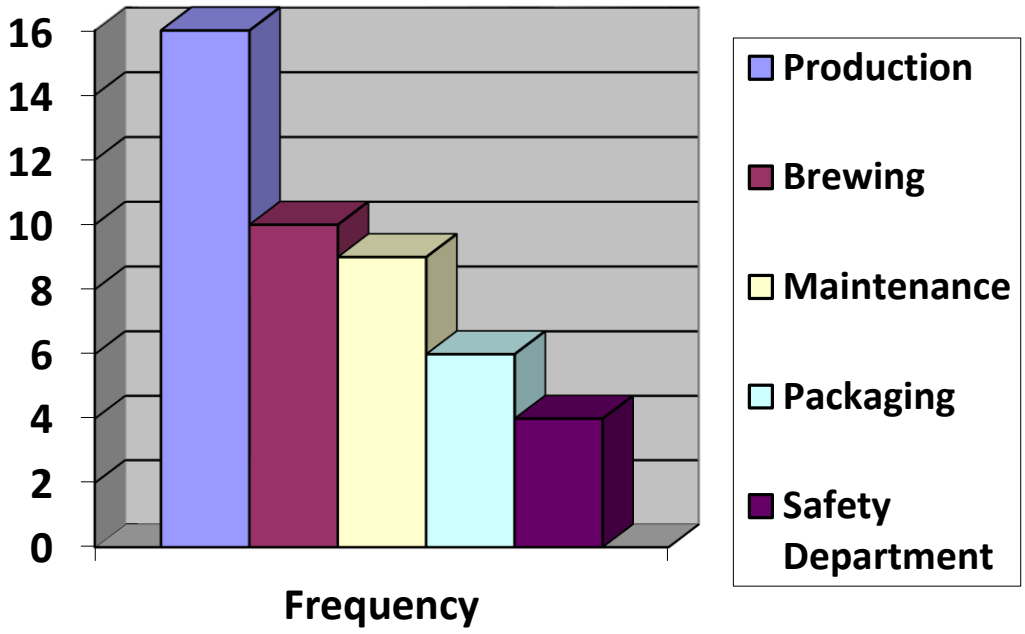
Table 4.2:1 Response Rate



The response rate shows that 90% of the questionnaires were successfully completed and returned, while only 10% were not returned. This is a strong response level, indicating high participation

and engagement from employees. In occupational safety studies, such a high response rate improves the reliability of the findings because it reduces the likelihood of missing or biased data. The fact that most employees participated suggests that workplace safety is a relevant and practical issue in their daily operations. It also reflects willingness among workers to share their experiences regarding PPE use and safety challenges. The low non-response rate shows that data loss was minimal and unlikely to affect overall results. The inclusion of interview participants further strengthens the depth of information collected. Overall, the response rate confirms that the dataset is sufficient for meaningful analysis of smart PPE effectiveness.

Table 4.2:2 Demographic Characteristics of Respondents



The statistics show that the production department contributed the highest proportion of respondents at 35.6%. This is expected because production is the core operational area where most workers are employed and where exposure to industrial hazards is highest. Brewing followed at 22.2%, which also involves significant exposure to heat, chemicals, and fermentation processes. Maintenance workers accounted for 20%, reflecting their frequent interaction with machinery and equipment breakdowns, which are high-risk activities. Packaging and safety departments had lower representation, but their inclusion ensures a more balanced view of workplace safety conditions. The distribution indicates that the study captured perspectives from both high-risk

operational areas and safety oversight roles. This balance improves the credibility of findings because it reflects actual workplace structure. Overall, the statistics show that the sample was appropriately distributed across key operational units.

Table 4.2:3 Working Experience

Experience	Frequency	Percentage
Less than 2 years	8	17.8%
2–5 years	15	33.3%
6–10 years	14	31.1%
Above 10 years	8	17.8%

The results show that the majority of respondents (33.3%) had between 2 and 5 years of experience, followed closely by those with 6 to 10 years at 31.1%. This indicates that most workers have moderate experience within the organization and are familiar with daily operational safety procedures. Employees within this range are likely to have encountered both routine safety practices and occasional incidents, making their views reliable for assessing PPE effectiveness. Those with less than 2 years of experience (17.8%) contribute newer perspectives, especially regarding adaptability to new technologies. Similarly, employees with more than 10 years of experience also represent 17.8%, offering long-term insights into safety trends and changes over time. The distribution shows a balanced mix of experience levels, which strengthens the validity of responses. It also ensures that the findings reflect both established and emerging workplace safety perceptions. Overall, the experience profile supports informed analysis of smart PPE adoption potential.

5 CHAPTER FIVE

DISCUSSIONS

5.1.1 Objective 1

Technical and Practical Challenges of Smart PPE Implementation

Table 4.2:1 Challenges

Challenge	Frequency	Percentage
High cost	18	40%
Limited technical knowledge	11	24.4%
Resistance to change	8	17.8%
Maintenance issues	5	11.1%
Connectivity issues	3	6.7%

The statistics clearly show that high cost is the most significant barrier, accounting for 40% of responses. This indicates that financial limitations are the primary concern when considering smart PPE adoption at Nyathi Breweries. Limited technical knowledge follows at 24.4%, showing that many workers may not fully understand how smart PPE operates or how to use it effectively. Resistance to change at 17.8% reflects behavioural hesitation, which is common when introducing new workplace technologies. Maintenance challenges (11.1%) suggest concerns about long-term usability and system reliability. Connectivity issues (6.7%) are the least reported but still relevant, especially for sensor-based systems requiring stable communication. Overall, the statistics show that barriers are both financial and human in nature. This implies that successful implementation would require training, investment, and change management strategies.

5.1.2 Objective 2

Effectiveness of Smart PPE in Reducing Injuries and Illnesses

Table 4.2:2 Perceived Effectiveness

Response	Frequency	Percentage
Very effective	20	44.4%
Effective	15	33.3%
Neutral	6	13.3%

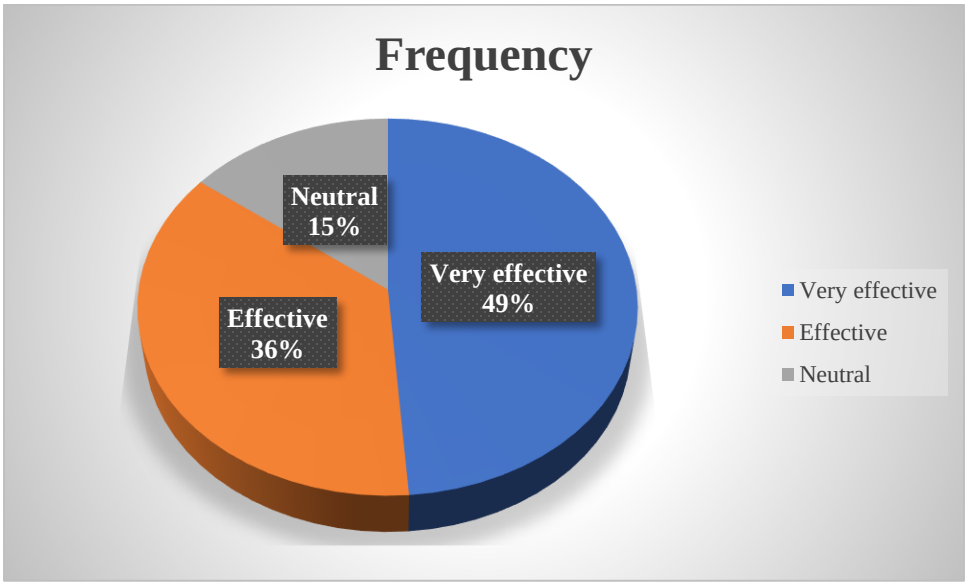


Figure 4.1 Responses on Perceived Effectiveness

From both the table and figure above, the statistics show a strong positive perception of smart PPE effectiveness, with 44.4% rating it as very effective and 33.3% as effective. This means that more than three-quarters of respondents (77.7%) believe smart PPE can significantly reduce injuries and illnesses. This strong approval suggests that workers recognize the limitations of conventional PPE, especially its inability to detect hazards in real time. The neutral responses (13.3%) may reflect uncertainty due to lack of exposure to smart PPE systems. Only a small proportion (8.9%) believe it would not be effective, indicating limited resistance to the concept. These findings suggest that acceptance levels are generally high among employees. The data implies that smart PPE could improve hazard awareness and early response in industrial settings. Overall, the statistics show strong potential for positive safety impact if implemented.

5.1.3 Objective 3
Improvements for Smart PPE Implementation

Table 4.2:3 Suggested Improvements

Improvement	Frequency	Percentage
Training	16	35.6%
Pilot testing	12	26.7%
Management support	9	20.0%
Technical support	5	11.1%
Policy integration	3	6.7%

The statistics indicate that training is the most important requirement, accounting for 35.6% of responses. This suggests that employees believe proper knowledge and skills are essential before introducing smart PPE. Pilot testing at 26.7% shows that respondents prefer gradual implementation rather than immediate full-scale adoption. Management support at 20% highlights the importance of leadership commitment in driving technological change. Technical support

(11.1%) reflects concerns about system maintenance and troubleshooting after deployment. Policy integration (6.7%) shows that formal organizational alignment is also necessary but considered less urgent by respondents. Overall, the results suggest that successful implementation depends on both human capacity and institutional support. The statistics emphasize that preparation and structured rollout are more important than immediate adoption.

5.2 Qualitative Findings.

5.2.1 Key themes

Four themes emerged from interviews and observations:

- Positive perception of smart PPE
- Financial constraints limiting adoption
- Need for continuous training
- Potential for improved safety compliance

These themes support the quantitative findings and show that while smart PPE is generally accepted, implementation barriers must be addressed. Workers appreciate the idea of real-time monitoring, but practical concerns such as cost and training remain central issues.

5.3 Discussion of Findings

This section discusses the major findings of the study on the applicability and effectiveness of Personal Protective Equipment (PPE) with integrated sensing technology at Nyathi Breweries. The discussion is organized according to the research objectives and links the empirical findings with relevant literature and occupational safety theories. The purpose is not only to interpret statistical results but also to explain their meaning in real workplace conditions within an industrial brewing environment. The chapter further examines how workers' perceptions, technical constraints, and organizational factors influence the potential adoption of smart PPE systems. In doing so, it situates the findings within broader debates on occupational safety innovation, behavioural compliance, and Industry 4.0 workplace technologies.

5.3.1 Technical and Practical Challenges of Smart PPE Implementation

The study found that the most significant barrier to implementing smart PPE at Nyathi Breweries is high cost, followed by limited technical knowledge, resistance to change, maintenance difficulties, and connectivity challenges. These findings suggest that although the technology is

recognized as useful, its adoption is constrained by structural and organizational limitations rather than rejection of its value. The prominence of cost as a barrier reflects the economic realities of many industrial organizations in developing contexts, where safety investments must compete with operational expenses.

These findings align with Rogers' Diffusion of Innovation Theory (2003), which explains that adoption of new technologies is often slowed by cost, complexity, and limited compatibility with existing systems. Similarly, the Technology Acceptance Model (Davis, 1989) highlights that perceived ease of use strongly influences whether workers accept new technologies. In this case, limited technical knowledge reduces confidence in using smart PPE, thereby affecting acceptance levels.

From a practical standpoint, the findings suggest that Nyathi Breweries is still operating within a transitional phase between traditional and digital safety systems. While workers recognise the benefits of smart PPE, the organizational readiness for full adoption is still limited. This supports Newaz et al. (2023), who argue that Industry 4.0 safety technologies often face implementation challenges in developing economies due to infrastructure and skills gaps. Overall, the results indicate that successful implementation requires financial planning, training, and gradual introduction rather than immediate replacement of conventional PPE.

5.3.2 Effectiveness of Smart PPE in Reducing Occupational Injuries and Illnesses.

The findings revealed that a large proportion of respondents believe smart PPE would be effective in reducing workplace injuries and illnesses. This positive perception indicates that workers recognize the limitations of conventional PPE, particularly its inability to provide real-time hazard detection. The idea of sensor-based alerts was strongly associated with improved safety awareness and faster response to danger.

These findings can be explained using Heinrich's Accident Causation Theory (1931), which argues that most workplace accidents are preventable and result from unsafe acts and conditions. Smart PPE directly addresses this by reducing delayed hazard recognition. The findings also align with Reason's Swiss Cheese Model (1990), which suggests that accidents occur when multiple safety barriers fail. Smart PPE adds an additional barrier by detecting hazards before they escalate into accidents.

Workers' responses also reflect growing awareness of predictive safety systems in modern occupational health and safety practice. Studies by Zhang and Li (2022) support the idea that sensor-based PPE improves early hazard detection and reduces exposure time to risks such as heat, noise, and chemical exposure. However, some uncertainty among respondents suggests limited exposure to the technology rather than opposition. This implies that familiarity plays a key role in shaping acceptance, consistent with TAM principles. Overall, the findings suggest that smart PPE has strong potential to improve occupational safety outcomes if effectively implemented within the brewery environment.

5.3.3 Improvements for Effective Implementation of Smart PPE.

The study identified training, pilot testing, management support, technical assistance, and policy integration as key requirements for successful implementation of smart PPE. Training emerged as the most important factor, indicating that workers require adequate knowledge before fully adopting the technology. This reflects Behaviour-Based Safety theory (Geller, 2001), which emphasizes that safe behaviour is reinforced through continuous learning and engagement.

Pilot testing was also strongly supported, suggesting that workers prefer gradual introduction of new technologies. This aligns with Kotter's Change Management Theory (1996), which highlights the importance of phased implementation and early success in managing organizational change. Management support was also considered critical, reflecting Cooper's Safety Culture Model (2000), which argues that leadership commitment strongly influences safety performance.

The need for technical support indicates concerns about system maintenance and reliability, while policy integration highlights the importance of aligning smart PPE with existing occupational safety frameworks. Overall, these findings suggest that implementation is not purely a technical process but an organizational transformation requiring coordination across all levels of the company.

5.4 Overall Interpretation of Findings

The overall findings suggest that smart PPE is viewed positively at Nyathi Breweries and is considered a promising tool for improving workplace safety. However, its successful implementation depends on addressing financial constraints, technical capacity gaps, and organizational readiness. Workers generally support the idea of real-time hazard detection, but practical limitations still restrict full adoption.

The findings further show that occupational safety at Nyathi Breweries is still largely dependent on conventional PPE systems, which are effective but limited in dynamic hazard detection. This creates a gap that smart PPE could potentially fill if properly introduced. The results also highlight that safety innovation is not only about technology but also about human behaviour, training, and management commitment.

Overall, the study confirms that workplace safety improvement requires a balanced integration of technology and organizational culture rather than relying on equipment alone.

5.5 Chapter Summary

This chapter presented and interpreted data collected from employees and management at Nyathi Breweries. The statistical findings show strong support for smart PPE effectiveness in improving workplace safety. However, financial, technical, and training challenges may affect implementation. The recommended charts include pie charts for proportions, bar charts for distributions, and horizontal bar charts for ranking challenges. Overall, the findings provide a clear foundation for discussion in the next chapter, where results are compared with existing literature and interpreted in broader academic context.

6 CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the conclusions drawn from the study and provides recommendations based on the findings. The conclusions are derived from the analysis of data collected at Nyathi Breweries. The recommendations are intended to improve occupational safety performance through the potential adoption of smart PPE with integrated sensing technology. They are directed toward management, employees, safety officers, and policymakers.

6.2 Summary of the study

Chapter One, provided a comprehensive introduction to the study by outlining the context, problem, and justification for evaluating smart PPE in a brewery industry. The background highlighted the evolution of occupational safety from traditional PPE systems to advanced smart technologies, emphasizing the limitations of passive protection in dynamic industrial environments. The problem statement identified persistent safety challenges despite existing PPE systems and highlighted the lack of empirical evidence on the effectiveness of smart PPE in Zimbabwean industrial settings. The research objectives and questions were then clearly defined to guide the study. The justification demonstrated the operational, academic, and policy relevance of the research, while delimitations and limitations clarified the scope and constraints of the study. Overall, the chapter establishes a strong foundation for investigating how smart PPE can contribute to improved occupational safety performance in industrial environments.

Chapter Two spells out the literature review. It explained the concepts related to the study, the definitions, and the theoretical framework. It covered the concepts of Smart PPE and Integrated Sensing Technology, and theoretical Frameworks in occupational safety and dissected local, regional and global trends in Smart PPE adoption substantiated with an empirical review.

Chapter Three presented the methodology used in the study, including the research design, study area, target population, sampling procedures, data collection methods, and data analysis techniques. It also outlined measures taken to ensure validity, reliability, and ethical compliance. The methodology provides a structured framework for evaluating the effectiveness and

applicability of smart PPE at Nyathi Breweries. It ensured that the findings are grounded in real industrial conditions and are both credible and academically robust.

Chapter Four presented and interpreted data collected from employees and management at Nyathi Breweries. The statistical findings show strong support for smart PPE effectiveness in improving workplace safety. However, financial, technical, and training challenges have an effect on implementation. Presentation of findings provided a clear foundation for discussion where results were compared with existing literature and interpreted in broader academic context.

6.3 Summary of Findings

6.3.1 Technical and Practical Challenges of Smart PPE Implementation

The study found that the most significant barrier to implementing smart PPE at Nyathi Breweries is high cost, followed by limited technical knowledge, resistance to change, maintenance difficulties, and connectivity challenges.

6.3.2 Effectiveness of Smart PPE in Reducing Occupational Injuries and Illnesses.

The findings revealed that a large proportion of respondents believe smart PPE would be effective in reducing workplace injuries and illnesses.

6.3.3 Improvements for Effective Implementation of Smart PPE.

The study identified training, pilot testing, management support, technical assistance, and policy integration as key requirements for successful implementation of smart PPE

The overall findings reveal that smart PPE is viewed positively at Nyathi Breweries and is considered a promising tool for improving workplace safety. However, its successful implementation depends on addressing financial constraints, technical capacity gaps, and organizational readiness. Workers generally support the idea of real-time hazard detection, but practical limitations still restrict full adoption.

The findings further show that occupational safety at Nyathi Breweries is still largely dependent on conventional PPE systems, which are effective but limited in dynamic hazard detection. This creates a gap that smart PPE could potentially fill if properly introduced. The results also highlight that safety innovation is not only about technology but also about human behaviour, training, and management commitment.

Overall, the study confirms that workplace safety improvement requires a balanced integration of technology and organizational culture rather than relying on equipment alone.

6.4 Conclusion

The study therefore concludes that smart PPE has strong potential to improve occupational safety in an industrial set up such as breweries, particularly through real-time hazard detection and improved situational awareness. Workers generally demonstrated positive attitudes toward the technology, indicating readiness for innovation in workplace safety systems. However, adoption is currently limited by high costs, insufficient technical knowledge, and resistance to change in some cases.

The study further concludes that conventional PPE, while still essential, is insufficient in addressing dynamic industrial hazards such as heat stress, chemical exposure, and machinery-related risks. Smart PPE offers a more proactive approach by enabling early detection and prevention of incidents before they occur.

Finally, the study concludes that successful implementation of smart PPE depends not only on technological availability but also on training, leadership support, and policy alignment. Without these supporting structures, adoption may remain limited despite its potential benefits.

6.5 Recommendations

The following recommendations are made, to the following:

6.5.1 Management

Management should introduce smart PPE gradually through pilot testing before full-scale implementation. This allows evaluation of cost, usability, and effectiveness under real operational conditions. Investment in safety technology should be viewed as a long-term productivity and risk reduction strategy.

6.5.2 Employees

Employees should actively participate in training programs related to smart PPE usage. A positive attitude toward technological change should be encouraged to improve acceptance and reduce resistance. Proper PPE use should remain a daily priority regardless of technology level.

6.5.3 Safety Officers

Safety officers should integrate smart PPE into existing occupational safety systems and ensure continuous monitoring. Regular training sessions and awareness campaigns should be conducted to improve understanding and compliance. They should also evaluate system performance regularly.

6.5.4 Policymakers and Regulators

Policy frameworks should be updated to support adoption of smart safety technologies in industrial sectors. Incentives such as subsidies or tax relief could encourage companies to invest in advanced PPE systems. Regulatory standards should also accommodate emerging Industry 4.0 safety innovations.

6.6 Areas for Further Research

Future studies should examine long-term effectiveness of smart PPE in industrial environments across different sectors. Comparative studies between conventional PPE and smart PPE would also provide deeper insight into cost-effectiveness. Further research could also explore employee behavioural adaptation to wearable safety technologies.

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Appendices

A. Questionnaire

Evaluating the Applicability and Effectiveness of Personal Protective Equipment with Integrated Sensing Technology at Nyathi Breweries

This questionnaire is designed for academic research purposes only. All responses will be treated with strict confidentiality and used solely for the purpose of this study.

SECTION A: DEMOGRAPHIC INFORMATION

1. Gender: Male / Female

2. Age Group: 18–25 / 26–35 / 36–45 / 46 and above

3. Highest Level of Education: Primary / Secondary / Diploma / Degree / Other

4. Department/Section: _____

5. Job Title/Position: _____

6. Years of Work Experience: <1 year / 1–5 years / 6–10 years / >10 years

SECTION B: KNOWLEDGE OF PERSONAL PROTECTIVE EQUIPMENT (PPE)

7. Do you use PPE in your daily work activities? Yes / No

8. How would you rate your knowledge of PPE usage? Very Good / Good / Fair / Poor

9. Have you ever received formal training on PPE use? Yes / No

10. How often is PPE training conducted in your workplace? Regularly / Occasionally / Rarely / Never

SECTION C: WORKPLACE HAZARDS

11. Which hazards are most common in your working environment? Chemical exposure / Heat stress / Noise exposure / Mechanical hazards / Slips and falls / Other

12. How frequently are you exposed to workplace hazards? Daily / Weekly / Occasionally / Rarely

13. Have you ever experienced a workplace injury or near-miss incident? Yes / No

SECTION D: USE OF SMART PPE (SENSING TECHNOLOGY PPE)

14. Are you aware of PPE with integrated sensing technology? Yes / No

15. If yes, how did you learn about smart PPE? Training / Colleagues / Management / Media/Internet / Other

16. Would you be willing to use smart PPE if introduced in your workplace? Yes / No / Not sure

17. What benefits do you expect from smart PPE? Real-time hazard detection / Improved safety / Reduced accidents / Health monitoring / Other

SECTION E: EFFECTIVENESS OF SMART PPE

Rate the following statements (1 = Strongly Disagree, 5 = Strongly Agree)

18. Smart PPE can improve early hazard detection. 1 2 3 4 5

19. Smart PPE can reduce workplace injuries. 1 2 3 4 5

20. Smart PPE improves safety compliance. 1 2 3 4 5

21. Smart PPE is easy to use in industrial operations. 1 2 3 4 5

22. Smart PPE provides more protection than traditional PPE. 1 2 3 4 5

SECTION F: CHALLENGES IN IMPLEMENTATION

23. Challenges affecting smart PPE use: High cost / Lack of training / Resistance to change / Technical issues / Maintenance / Privacy concerns

24. Do you think management is ready to adopt smart PPE? Yes / No / Not sure

SECTION G: IMPROVEMENT AND RECOMMENDATIONS

25. What should be done to improve safety at Nyathi Breweries?

_____

_____

26. What improvements would you suggest for effective use of smart PPE?

_____

_____

THANK YOU FOR YOUR PARTICIPATION

B. INTERVIEW GUIDE

Research Title: **Applicability and Effectiveness of Personal Protective Equipment with Integrated Sensing Technology at Nyathi Breweries in Harare, Zimbabwe**

Target Participants: Safety Officers, Operations Managers, and Floor Supervisors

Participant Information & Consent

Introduction: Brief explanation of the research purpose, confidentiality guarantees, and audio-recording consent.

Part 1: Operational Baseline & Current Safety Framework (Context)

- What are the most frequent occupational hazards encountered on the production floor?
- How effective is the current conventional PPE in mitigating these specific risks?
- What main limitations have you observed with passive, traditional safety gear?
- How often do near-misses occur due to delayed hazard detection?

Part 2: Technical & Practical Implementation Challenges

- What infrastructure challenges (e.g., connectivity, power, charging) exist for deploying smart PPE?
- How have workers reacted to wearing gear equipped with physiological or tracking sensors?
- What maintenance, calibration, or durability issues have emerged during shifting production environments?
- How does the cost of smart PPE impact your department's procurement budget?

Part 3: Effectiveness in Reducing Injuries & Illnesses

- In what ways have real-time sensor alerts changed response times during high-risk events?
- Have you observed a quantifiable drop in specific injuries (e.g., heat stress, noise exposure) since introducing smart technology?
- How do sensor metrics compare against traditional self-reported safety logs for accuracy?
- How does real-time monitoring alter supervisor enforcement and worker compliance habits?

Part 4: Recommendations for Optimization

- What technical modifications does this smart gear require to better fit brewery operations?
- What training or organizational policies are needed to improve worker acceptance of smart safety technology?
- How can data privacy concerns regarding physiological tracking be best managed?