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(REVIEW ARTICLE)

A systematic review of safety assessment and occupational risk among roadside vulcanizers in Nigeria

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Abstract

Roadside vulcanizers constitute an essential part of Nigeria's informal economy, providing affordable tyre repair services across urban and rural communities. Despite their importance, their work exposes them to significant occupational hazards that remain largely unaddressed by research, policy, and formal safety systems. This review examines the current state of occupational safety and risk management among roadside vulcanizers, highlighting key hazards such as chemical exposure to volatile organic compounds, fire and explosion risks, injuries from heated equipment and sharp tools, ergonomic strain from manual tyre handling, and environmental stressors including air pollution, noise, and harsh weather. Evidence from existing literature and occupational health frameworks reveals that these workers often operate without adequate ventilation, protective equipment, training, or regulatory oversight. Socioeconomic factors further intensify these risks, as limited income, low safety awareness, and poor access to healthcare compel workers to prioritize daily earnings over safe practices. The informal nature of the sector leaves them highly vulnerable to both acute injuries and long-term health conditions. The study underscores the need for targeted, context-appropriate interventions. It recommends developing safety guideline suited to informal workshops, expanding community-based training programs, improving access to affordable occupational health services, and promoting collaborative regulatory approaches involving government agencies, trade associations, and worker groups. Ensuring the safety of roadside vulcanizers requires an integrated strategy that enhances protection, supports economic realities, and strengthens institutional capacity within Nigeria's informal automotive repair sector.

Keywords: Roadside Vulcanizers; Occupational Health; Informal Automotive Repair Sector; Safety Assessment; Chemical Exposure; Ergonomic Hazards; Musculoskeletal Disorders; Risk Analysis; Nigeria

1. Introduction

Roadside vulcanizers in Nigeria constitute a vital component of the country's informal automotive service sector, providing accessible and affordable tire repair services to millions of vehicle owners across the nation (Afolabi, de Beer and Haaf kens, 2021; Ozonate, 2024). These workers typically operate in makeshift workshops along major highways, in motor parks, and within urban centers, serving as the primary source of tire maintenance and repair for a significant portion of Nigeria's vehicular population. The vulcanizing trade has evolved as a response to the country's challenging road conditions, high vehicle maintenance costs, and the need for immediate tire repair services in areas where formal automotive service centers are scarce or expensive (Johnson and Bassey, 2016). The demographic composition of roadside vulcanizers in Nigeria is predominantly young males, many of whom enter the trade through informal apprenticeship systems without formal training in occupational safety and health practices (Oche et al., 2020; Sambo, Idris and Shaming, 2023). This workforce often lacks access to proper safety equipment, training programs, and

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regulatory oversight, making them particularly vulnerable to occupational hazards. The economic necessity that drives individuals into this profession often overshadows safety considerations, creating a work environment where immediate income generation takes precedence over long-term health and safety concerns (Afolabi, de Beer and Haaf kens, 2021).

The operations of roadside vulcanizers typically involve a range of activities, including tyre removal and installation, patch repairs, tube replacement, and vulcanization processes using various chemicals and heated equipment (Omophorion, 1999). These activities are performed in environments that lack proper ventilation, safety infrastructure, and emergency response capabilities. The informal nature of these operations means that workers are often exposed to multiple hazards simultaneously without adequate protective measures or awareness of potential health risks (Ozonate, Dubem and Osegueda, 2021). The socioeconomic importance of roadside vulcanizers cannot be overstated, as they provide employment opportunities for thousands of individuals while delivering essential services to the transportation sector (Ebikake-Anyanwu and Warper, 2025). However, the lack of formal recognition and regulation of this sector has resulted in a significant gap in occupational safety and health protection for these workers. Understanding the safety challenges faced by roadside vulcanizers is crucial for developing appropriate interventions and policy frameworks to protect this vulnerable workforce while maintaining their vital contribution to Nigeria's economy (Federal Ministry of Labor and Employment, 2012).

2. Regulatory Framework and Occupational Safety Context

The regulatory landscape governing occupational safety and health in Nigeria is primarily anchored by the Factories Act of 2004 and the National Policy on Occupational Safety and Health launched in 2006, which provide the legal framework for workplace safety standards and requirements (Federal Ministry of Labour and Employment, 2012). However, these regulations were primarily designed for formal sector establishments and have limited applicability to informal sector workers such as roadside vulcanizers. The informal nature of vulcanizing operations means that most workers operate outside the purview of regulatory oversight, creating a significant gap in safety protection and enforcement (Ebikake-Nwanyanwu and Woripre, 2025). The Nigerian government has recognized the importance of occupational safety and health through various policy initiatives, including the establishment of the Federal Ministry of Labour and Employment's Occupational Safety and Health Department. However, the implementation of safety standards in the informal sector remains challenging due to limited resources, inadequate inspection capabilities, and the scattered nature of roadside vulcanizing operations. This regulatory gap has resulted in a situation where workers are largely responsible for their own safety without access to proper guidance, training, or enforcement mechanisms.

Professional organizations and trade associations in Nigeria have attempted to fill some of these regulatory gaps through voluntary safety initiatives and training programs. However, the reach and effectiveness of these efforts are limited by funding constraints, a lack of standardized training materials, and the transient nature of many roadside vulcanizing operations. The absence of mandatory safety training and certification requirements for vulcanizers has contributed to widespread safety knowledge gaps and poor adherence to basic safety practices. International occupational safety and health standards, such as those developed by the International Labour Organization (ILO), provide valuable frameworks for addressing workplace hazards in the tyre repair industry (International Labour Organization, 2021). However, the adaptation and implementation of these standards in Nigeria's informal sector context require significant modifications to account for resource constraints, cultural factors, and the unique operational characteristics of roadside vulcanizers. The development of context-appropriate safety guidelines and regulations remains a critical need for improving the occupational safety and health outcomes of this workforce.

3. Occupational Hazards Among Roadside Vulcanizers

Roadside vulcanizers are faced with some hazards (Figure 1), which include: physical, chemical, environmental, and ergonomic hazards.

3.1. Chemical Exposure Risks

Roadside vulcanizers in Nigeria are routinely exposed to a wide array of hazardous chemicals during their daily operations, creating significant health risks that are often underestimated or ignored due to lack of awareness and protective measures (Afolabi, de Beer and Haaf kens, 2021). The vulcanization process involves the use of various chemical substances including rubber cement, petroleum-based solvents, adhesives, and cleaning agents that contain toxic compounds such as benzene, toluene, xylene, and other volatile organic compounds (VOCs). These chemicals pose both acute and chronic health risks, including respiratory problems, skin irritation, neurological effects, and

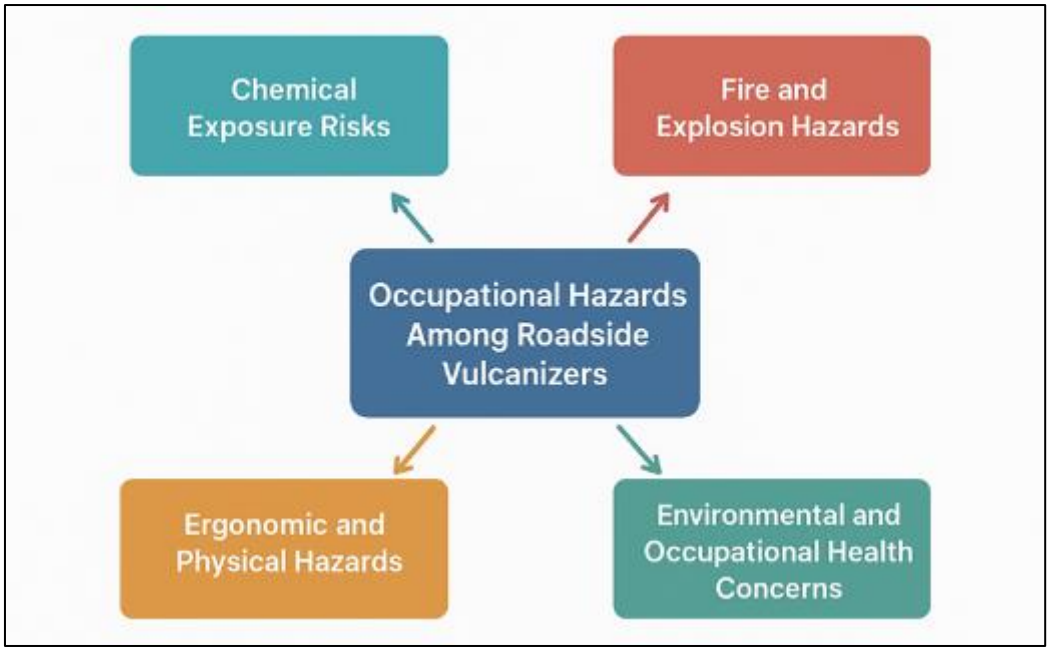

Figure 1 Occupational Hazards Among Roadside Vulcanizers

potential carcinogenic exposures (Udonwa et al., 2009). The most significant chemical hazard faced by roadside vulcanizers is exposure to rubber cement and solvents used in the tyre patching process (Saliu et al., 2015). These substances typically contain high concentrations of organic solvents that can cause immediate effects such as dizziness, headaches, and respiratory irritation, as well as long-term health consequences including liver damage, kidney dysfunction, and neurological impairment. The practice of working in poorly ventilated environments exacerbates these risks, as workers are exposed to high concentrations of chemical vapors for extended periods without adequate respiratory protection (Ozomata, Odugbemi and Osagiede, 2021).

Carbon black, a common component in tyre manufacturing and repair materials, represents another significant chemical hazard for vulcanizers. Extended exposure to carbon black dust can lead to respiratory problems, including pneumoconiosis and other lung diseases. The International Agency for Research on Cancer (IARC) has classified carbon black as a Group 2B carcinogen, indicating possible carcinogenic effects in humans. Roadside vulcanizers often work with materials containing carbon black without proper dust control measures or respiratory protection, increasing their risk of developing occupational lung diseases. The improper storage and handling of chemical substances in roadside vulcanizing operations create additional risks for workers and the surrounding environment. Many vulcanizers store flammable solvents and adhesives in inadequate containers without proper labeling or safety precautions, increasing the risk of chemical spills, fires, and explosions. The lack of proper waste disposal procedures for used chemicals and contaminated materials also contributes to environmental contamination and potential health risks for workers and nearby communities.

3.2. Fire and Explosion Hazards

The nature of roadside vulcanizing operations inherently involves significant fire and explosion risks due to the combination of flammable chemicals, heating equipment, and often inadequate safety measures (Omokhodion, 1996). Vulcanizers regularly work with petroleum-based solvents, rubber cement, and other flammable substances while using open flames, hot plates, and heating equipment for the vulcanization process. This combination creates a potentially volatile work environment where fire and explosion accidents can occur with devastating consequences for workers and nearby properties (Ozomata, 2024). The heating equipment used in vulcanizing operations, including gas burners, electric hot plates, and portable heating devices, often lacks proper safety features and maintenance protocols. Many roadside vulcanizers use improvised heating equipment that does not meet safety standards, increasing the risk of equipment malfunction, gas leaks, and accidental ignition of flammable materials. The absence of proper fire suppression systems, emergency shutdown procedures, and evacuation plans further compounds these risks, leaving workers vulnerable to serious injuries or fatalities in the event of a fire or explosion.

Static electricity generation during tyre handling and chemical use presents another fire hazard that is often overlooked by roadside vulcanizers. The movement of tyres, handling of plastic materials, and pouring of solvents can generate

static electrical charges that may ignite flammable vapors in the work environment. The lack of proper grounding procedures, antistatic equipment, and humidity control measures increases the risk of static electricity-related fires and explosions. The storage and handling of pressurized gas cylinders used for heating and inflation equipment also pose significant explosion risks. Many roadside vulcanizers lack proper training in cylinder handling, storage procedures, and leak detection methods, leading to unsafe practices that can result in cylinder explosions or gas leaks. The absence of proper cylinder storage facilities, safety valves, and emergency response procedures further increases the risk of serious accidents involving pressurized gas systems.

3.3. Ergonomic and Physical Hazards

Roadside vulcanizers in Nigeria are subjected to numerous ergonomic hazards that significantly increase their risk of developing musculoskeletal disorders (MSDs) and repetitive strain injuries throughout their careers (Onawumi et al., 2022). The nature of tyre repair work involves prolonged periods of awkward posturing, including bending, kneeling, squatting, and working in cramped positions while removing and installing tyres. These sustained awkward postures place excessive stress on the spine, joints, and supporting musculature, leading to the development of chronic back pain, joint stiffness, and other musculoskeletal problems (Ajayeoba et al., 2016). The manual handling of heavy tyres and wheels represents a major ergonomic risk factor for roadside vulcanizers (Ajayeoba et al., 2016). Commercial vehicle tyres, in particular, can weigh between 50-100 kilograms or more, requiring significant physical effort to maneuver during removal, repair, and installation processes. The lack of proper lifting equipment, mechanical aids, and lifting techniques training exposes workers to high risks of acute back injuries, herniated discs, and chronic spine problems (Ajayeoba, 2019). The repetitive nature of tyre handling throughout the workday further compounds these risks, as workers perform similar lifting and carrying motions hundreds of times per week without adequate recovery periods. The work environment of roadside vulcanizers often lacks proper work surfaces, seating arrangements, and ergonomic tools that could reduce physical strain and improve working postures (Enwerem et al., 2017). Many vulcanizers work directly on the ground or use makeshift work surfaces that require excessive bending and reaching motions. The absence of adjustable workbenches, proper lighting, and organized tool storage systems forces workers to adopt uncomfortable positions for extended periods, increasing the risk of developing cumulative trauma disorders and repetitive strain injuries (Ajayeoba et al., 2016).

Vibration exposure from power tools, air compressors, and other equipment used in vulcanizing operations contributes to the development of hand-arm vibration syndrome (HAVS) and other vibration-related disorders (Raheem et al., 2019). The prolonged use of pneumatic tools, grinding equipment, and portable compressors without proper vibration dampening or rotation of tasks exposes workers to harmful levels of vibration that can cause nerve damage, circulatory problems, and reduced hand function over time (Onawumi et al., 2022).

3.4. Environmental and Occupational Health Concerns

Vulcanizers are an integral part of road transport systems because they offer necessary tyre repair and maintenance services. Despite their significance, roadside vulcanisers are subject to serious occupational health and environmental hazards due to their working conditions. Tire inflation, patching, rim handling, and the use of chemical adhesives or compressed air are examples of everyday tasks that expose employees to heat, noise, airborne particles, and dangerous materials. Furthermore, the informal character of the employment frequently leads to poor workplace organisation, insufficient usage of personal protective equipment, and inadequate safety procedures. In addition to raising the risk of accidents, these illnesses also raise the risk of chronic health issues. Some of these problems are:

Air Quality and Respiratory Health: The air quality in roadside vulcanizing work environments is typically compromised by multiple sources of air pollution that pose significant respiratory health risks to workers (Udonwa et al., 2009). Vehicle exhaust emissions from the constant flow of traffic create elevated levels of particulate matter, nitrogen oxides, carbon monoxide, and other harmful pollutants that workers inhale throughout their workday. The roadside location of most vulcanizing operations means that workers are continuously exposed to these traffic-related air pollutants in addition to occupational chemical exposures, creating a cumulative respiratory health burden (Omokhodion, 1999). Dust generation from tyre grinding, sanding, and handling activities contributes significantly to poor air quality in vulcanizing workspaces. The dust particles released during these operations contain various harmful substances, including carbon black, silica, and other tyre components that can cause respiratory irritation and long-term lung damage.

The absence of dust control measures, ventilation systems, and respiratory protection equipment means that workers are chronically exposed to these harmful particles at levels that exceed recommended occupational exposure limits. The combustion of solid fuels and waste materials for heating and lighting purposes in many roadside vulcanizing operations creates additional air quality concerns. Workers often burn wood, charcoal, paper, and other combustible

materials in poorly ventilated areas, resulting in the release of smoke, particulate matter, and toxic gases that can cause acute respiratory symptoms and contribute to chronic respiratory diseases. The practice of burning waste materials, including used tyres and contaminated rags, can release highly toxic substances including dioxins and other persistent organic pollutants. Seasonal variations in air quality, particularly during the harmattan season in northern Nigeria, can exacerbate respiratory health risks for roadside vulcanizers. The combination of dust-laden harmattan winds with occupational dust exposure creates particularly challenging conditions for workers with pre-existing respiratory conditions or those who have developed occupational lung diseases. The lack of respiratory protection and air quality monitoring in most vulcanizing operations means that workers are unaware of their exposure levels and the associated health risks.

Noise Exposure and Hearing Conservation: Roadside vulcanizers are exposed to hazardous noise levels from multiple sources, including traffic noise, pneumatic tools, air compressors, and other mechanical equipment used in tyre repair operations (Onawumi et al., 2022). The combination of occupational noise exposure with ambient traffic noise creates a particularly challenging acoustic environment that can exceed safe exposure limits and contribute to noise-induced hearing loss over time. The continuous nature of this noise exposure, combined with the lack of hearing protection, places workers at high risk for developing permanent hearing damage (Johnson and Bassey, 2016). Air compressors used for tyre inflation and pneumatic tool operation are significant sources of occupational noise exposure in vulcanizing operations. These devices often operate at noise levels exceeding 85 decibels, the threshold for mandatory hearing protection in most occupational safety standards. The prolonged operation of compressors in close proximity to workers, combined with poor acoustic design of work areas, creates conditions that can lead to both temporary and permanent hearing loss among vulcanizers.

The acoustic environment of roadside vulcanizing operations is further complicated by the lack of noise control measures and sound-absorbing materials in most work areas. The hard surfaces, metal structures, and open-air nature of most vulcanizing operations create acoustic conditions that amplify and reflect noise, increasing overall exposure levels. The absence of noise barriers, acoustic treatments, and proper equipment maintenance contributes to higher noise levels than would be experienced in properly designed work environments. Communication challenges arising from high noise levels can create additional safety hazards for roadside vulcanizers. The difficulty of hearing warning signals, verbal communications, and approaching vehicles in noisy environments increases the risk of accidents and injuries. The lack of alternative communication methods, such as visual signals or vibrating devices, means that workers may not receive important safety information or warnings in time to prevent accidents.

4. Workplace Injuries and Trauma

The roadside vulcanizing work environment presents numerous opportunities for acute injuries and trauma due to the combination of sharp tools, heavy equipment, moving machinery, and often hazardous working conditions. Cuts and lacerations from sharp metal objects, broken glass, and improvised tools are among the most common injuries reported by vulcanizers. The use of makeshift tools, damaged equipment, and inadequate safety devices increases the likelihood of serious cuts that may require medical attention and result in lost work time. Burns, bruises, headache/dizziness, and cuts were the most reported work-related illnesses and injuries among roadside automobile mechanics, including vulcanizers, highlighting the prevalence of these injury types in the informal automotive repair sector (Johnson and Bassey, 2016). Burns from hot surfaces, chemical splashes, and contact with heated vulcanizing equipment are particularly common due to the nature of the work and often inadequate personal protective equipment (Ozomata, 2024). The severity of burn injuries can range from minor skin irritation to serious third-degree burns requiring hospitalization and potentially causing permanent disability.

Eye injuries represent another significant hazard for roadside vulcanizers, particularly during grinding, cutting, and chemical handling operations. The absence of proper eye protection, combined with the prevalence of flying debris, chemical splashes, and bright welding or cutting flames, creates high risks for acute eye injuries that can result in vision impairment or blindness. The dusty and contaminated work environment further increases the risk of eye irritation and infection, particularly for workers who do not use appropriate eye protection consistently. Slip, trip, and fall injuries are common in roadside vulcanizing operations due to cluttered work areas, oil spills, uneven surfaces, and inadequate lighting conditions. Many vulcanizers work in areas with poor housekeeping practices, scattered tools and equipment, and surfaces contaminated with oil, grease, and other slippery substances. The absence of proper walkways, adequate lighting, and organized storage systems increases the risk of serious falls that can result in fractures, head injuries, and other traumatic injuries requiring immediate medical attention.

5. Socioeconomic Factors and Vulnerability

Vulcanizers contribute significantly to traffic safety by offering tyre repair and maintenance services, frequently in unofficial roadside locations. Despite the significance of their employment, many vulcanisers labour in difficult socioeconomic environments that make them more susceptible to workplace dangers. Increased exposure to physical, chemical, and ergonomic hazards as a result of their informal work environment, low income, lack of education, and insufficient access to safety gear. Determining the underlying causes of their vulnerability and creating successful solutions require an understanding of the socioeconomic elements that influence their everyday lives. This conversation looks at how these elements affect vulcanisers' general well-being, safety, and health in their communities.

5.1. Economic Pressures and Safety Trade-offs

The economic circumstances of roadside vulcanizers in Nigeria significantly influence their approach to occupational safety and health, often creating situations where immediate income generation takes precedence over long-term health and safety considerations (Ajayeoba, Adebiyi and Raheem, 2018). The informal nature of the vulcanizing trade means that workers typically operate without fixed incomes, social security benefits, or health insurance coverage, making them particularly vulnerable to the financial impacts of work-related injuries and illnesses. This economic vulnerability creates pressure to continue working despite hazardous conditions, injuries, or health problems that would normally warrant rest or medical attention (Nwobi et al., 2021). The competitive nature of the roadside vulcanizing market often drives down service prices, forcing workers to prioritize speed and cost-effectiveness over safety measures (Adebiyi, Jekayinfa and Charles-Owaba, 2005). Vulcanizers may skip safety procedures, use inferior materials, or work in unsafe conditions to reduce costs and complete repairs quickly in order to attract customers and maintain their market position. This economic pressure creates a cycle where safety investments are viewed as unnecessary expenses rather than essential protective measures, perpetuating hazardous working conditions (Adebiyi and Ajayeoba, 2011).

The lack of access to formal credit and financial services limits the ability of roadside vulcanizers to invest in safety equipment, proper tools, and workspace improvements. Many workers operate with minimal capital and cannot afford to purchase personal protective equipment, upgrade their tools, or improve their work environments. The absence of financial support mechanisms, such as microfinance programs or safety equipment subsidies, means that workers must choose between immediate income generation and long-term safety investments. The informal employment arrangements common in roadside vulcanizing operations often lack worker compensation mechanisms for injuries or illnesses, creating additional economic disincentives for safety compliance. Workers who are injured on the job typically bear the full financial burden of medical treatment and lost income, making it economically rational to avoid safety measures that might slow down work or increase costs. This economic reality creates a fundamental conflict between worker safety and economic survival in the informal sector.

5.2. Educational and Training Gaps

The educational background and training pathways of roadside vulcanizers in Nigeria significantly impact their understanding of occupational safety and health principles and their ability to implement effective safety measures in their work (Makanjuola, 2019). Many vulcanizers enter the trade through informal apprenticeship systems that focus primarily on technical skills without providing comprehensive safety training or education. This skills-focused approach often overlooks fundamental safety concepts, hazard recognition, and risk management principles that are essential for preventing work-related injuries and illnesses (Sambo, Idris and Shamang, 2023). The literacy levels and formal education backgrounds of many roadside vulcanizers may limit their ability to access and understand written safety information, technical manuals, and regulatory requirements. This educational gap creates challenges in communicating safety concepts, implementing safety programs, and ensuring compliance with safety standards. The absence of safety training materials in local languages and culturally appropriate formats further compounds these communication barriers and limits the effectiveness of safety education initiatives.

The informal nature of skill transmission in roadside vulcanizing operations means that unsafe practices and attitudes toward safety are often perpetuated from master craftsmen to apprentices. Without formal safety training requirements or standardized curricula, apprentices may learn inadequate safety practices and develop poor safety habits that persist throughout their careers. This intergenerational transmission of unsafe practices creates systemic safety problems that are difficult to address through conventional training approaches. The lack of continuing education and professional development opportunities for roadside vulcanizers limits their ability to stay current with evolving safety technologies, regulations, and best practices. Unlike workers in formal sector establishments who may receive regular safety training and updates, roadside vulcanizers typically operate in isolation without access to professional development resources or peer learning opportunities. This isolation contributes to the persistence of outdated and unsafe practices even when better alternatives are available.

6. Approaches to Improving the Safety of Vulcanizers

Addressing the concerns of health and injuries with the roadside vulcanizers requires a comprehensive safety approach that combines proper training, improved work practices, environmental controls, and the use of appropriate protective tools. Some of these approaches as shown in Figure 2, include:

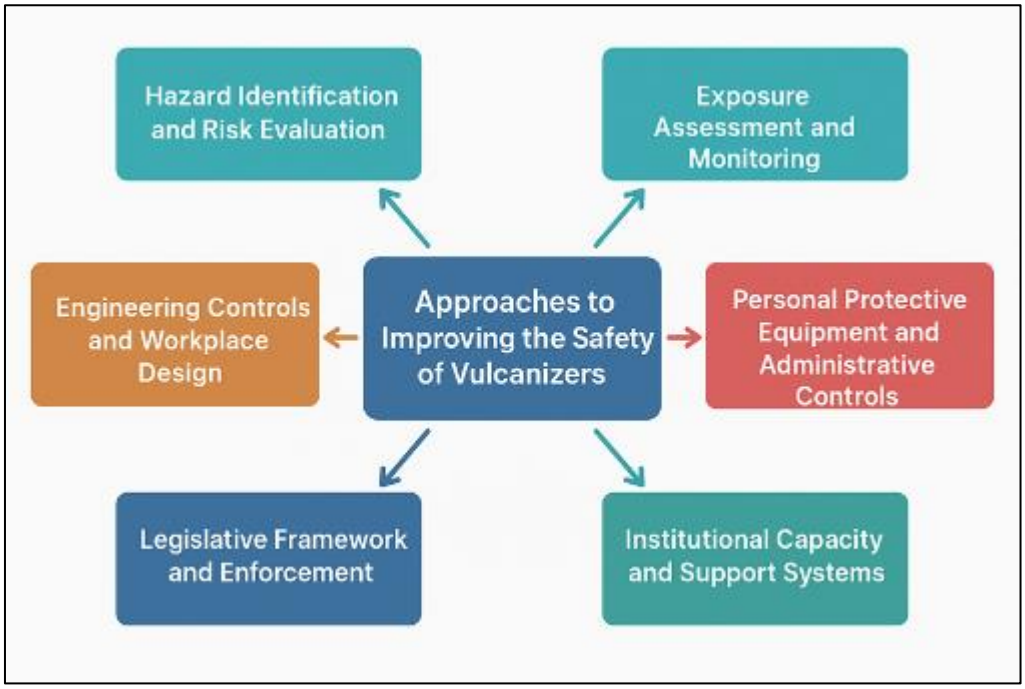

Figure 2 Approaches to Improving the Safety of Vulcanizers

6.1. Hazard Identification and Risk Evaluation

The process of hazard identification and risk evaluation for roadside vulcanizers in Nigeria requires a comprehensive approach that addresses the unique characteristics of informal sector operations and the multiple hazards present in this work environment (Umeokafor et al., 2014). Traditional risk assessment methodologies developed for formal sector establishments may not be directly applicable to roadside vulcanizing operations due to the variable nature of work conditions, limited documentation, and absence of standardized procedures. However, adapted risk assessment approaches can provide valuable insights into the primary hazards and risks faced by this workforce (Kohn et al., 2023). The identification of chemical hazards in roadside vulcanizing operations requires consideration of both the direct chemicals used in tyre repair processes and the indirect exposures from environmental sources such as traffic emissions and contaminated materials. A comprehensive chemical hazard assessment should include evaluation of rubber cement solvents, adhesives, cleaning agents, and other chemical substances used in vulcanizing operations. The assessment should also consider the potential for chemical interactions, degradation products, and cumulative exposures that may occur in the complex chemical environment of roadside operations.

Physical hazard identification must account for the diverse range of equipment, tools, and environmental conditions encountered in roadside vulcanizing operations. The assessment should evaluate hazards related to manual handling, powered equipment, heating devices, pressurized systems, and environmental factors such as noise, vibration, and temperature extremes. The variable nature of roadside operations means that hazard identification must be flexible enough to account for seasonal variations, different work locations, and the range of equipment and materials used by different vulcanizers. The risk evaluation process for roadside vulcanizers should incorporate both quantitative and qualitative assessment methods to account for the limited availability of exposure data and the need for practical risk management solutions. Quantitative assessments may include air monitoring for chemical exposures, noise level measurements, and ergonomic evaluations where feasible. Qualitative assessments should focus on systematic observation of work practices, evaluation of safety controls, and assessment of worker knowledge and behavior patterns that influence risk levels.

6.2. Exposure Assessment and Monitoring

Exposure assessment for roadside vulcanizers in Nigeria faces significant challenges due to the informal nature of operations, limited resources for monitoring equipment, and the highly variable nature of work environments. However, exposure assessment remains a critical component of understanding the health risks faced by this workforce and developing appropriate protective measures (Ossai and Fauziah, 2024). The approach to exposure assessment must be adapted to the constraints and characteristics of roadside vulcanizing operations while maintaining scientific rigor and practical applicability. Personal exposure monitoring for chemical substances used in vulcanizing operations requires consideration of the specific chemicals present, their volatility, and the duration and frequency of exposure. Air monitoring for organic solvents, particulate matter, and other airborne contaminants can provide valuable data on exposure levels and their relationship to health effects. However, the cost and complexity of personal monitoring equipment may limit its practical application in most roadside operations, requiring the development of alternative assessment approaches such as surrogate monitoring and exposure modeling.

Biological monitoring approaches may offer practical alternatives to air monitoring for assessing chemical exposures among roadside vulcanizers. Biomarkers of exposure, such as urinary metabolites of organic solvents or blood levels of absorbed chemicals, can provide integrated measures of exposure that account for all routes of absorption. However, the implementation of biological monitoring programs requires access to appropriate laboratory facilities and trained personnel, which may be limited in many areas of Nigeria. The assessment of physical hazards such as noise, vibration, and ergonomic factors requires appropriate measurement instruments and protocols adapted to the roadside work environment. Sound level meters, vibration analyzers, and ergonomic assessment tools can provide objective measures of exposure levels, but their use requires training and quality control procedures to ensure accurate and reliable results. The development of simplified assessment protocols and the use of screening tools may be necessary to make exposure assessment more practical and accessible for roadside vulcanizing operations.

6.3. Engineering Controls and Workplace Design

The implementation of engineering controls in roadside vulcanizing operations faces unique challenges due to the informal nature of these workplaces, limited financial resources, and the often temporary or mobile nature of operations (Ajayeoba, Raheem and Adebiyi, 2019). However, well-designed engineering controls can provide the most effective long-term protection for workers by eliminating or reducing hazards at their source. The development of appropriate engineering controls for roadside vulcanizers requires innovative approaches that balance effectiveness with practicality and cost considerations (Adebiyi and Ajayeoba, 2015). Ventilation systems represent one of the most important engineering controls for reducing chemical exposures in vulcanizing operations. Local exhaust ventilation systems designed specifically for tyre repair operations can capture chemical vapors and fumes at their source, preventing their dispersion into the work environment. However, the implementation of traditional ventilation systems may be challenging in roadside operations due to power requirements, space constraints, and mobility considerations. Alternative approaches such as natural ventilation enhancement, portable exhaust systems, and work practice modifications may be more practical for many roadside vulcanizers.

The design of work surfaces and equipment arrangements can significantly impact worker exposure to ergonomic hazards and improve overall workplace safety (Adebiyi et al., 2016). Adjustable work benches, tyre handling equipment, and organized tool storage systems can reduce the physical demands of vulcanizing work and minimize exposure to musculoskeletal risks (Enwerem et al., 2017). The development of portable or modular workplace design solutions that can be easily transported and set up in different locations may be particularly valuable for roadside vulcanizers who frequently change work locations. Fire prevention and suppression systems are critical engineering controls for addressing the significant fire and explosion risks in vulcanizing operations (Adebiyi, Ajayeoba and Raheem, 2019). The installation of appropriate fire suppression systems, explosion-proof electrical equipment, and emergency shutdown systems can significantly reduce the risk of serious fires and explosions. However, the implementation of these systems in roadside operations requires careful consideration of power requirements, maintenance needs, and the mobile nature of many vulcanizing operations (Segi, Ogoniba and Joy, 2023).

6.4. Personal Protective Equipment and Administrative Controls

Personal protective equipment (PPE) represents a crucial line of defense for roadside vulcanizers against occupational hazards, particularly in situations where engineering controls are not feasible or provide incomplete protection (Ozomata, Odugbemi and Osagiede, 2021). The selection and use of appropriate PPE for vulcanizing operations requires careful consideration of the specific hazards present, the work environment conditions, and the practical constraints faced by informal sector workers. Effective PPE programs must address not only the technical specifications of protective equipment but also issues related to cost, availability, comfort, and user acceptance (Makanjuola, 2019).

Respiratory protection is essential for vulcanizers working with chemical substances, in dusty environments, or in areas with poor air quality. The selection of appropriate respiratory protection depends on the specific contaminants present, their concentrations, and the duration of exposure. Half-face respirators with appropriate cartridges may be suitable for protection against organic vapors from solvents and adhesives, while dust masks or filtering facepieces may be appropriate for protection against particulate matter. However, the effectiveness of respiratory protection depends on proper fit testing, maintenance, and consistent use, which may be challenging to achieve in informal sector operations.

Hand and skin protection are critical for preventing chemical exposures and reducing the risk of cuts, burns, and dermatological problems. Chemical-resistant gloves, protective clothing, and barrier creams can provide effective protection against many of the hazards encountered in vulcanizing operations. The selection of appropriate hand protection must consider the specific chemicals used, the dexterity requirements of the work, and the durability needs of the application. Training in proper glove selection, use, and disposal is essential for ensuring effective protection. Administrative controls, including safety training, work practice modifications, and hazard communication programs, play a crucial role in preventing occupational injuries and illnesses among roadside vulcanizers (Ajayeoba and Adebiyi, 2017). Safety training programs should address hazard recognition, safe work practices, emergency procedures, and the proper use of protective equipment. However, the development of effective training programs requires consideration of educational backgrounds, language barriers, and cultural factors that may influence learning and behavior change (Sambo, Idris and Shamang, 2023).

6.5. Legislative Framework and Enforcement

The development of an effective regulatory framework for protecting roadside vulcanizers in Nigeria requires a comprehensive approach that addresses the unique characteristics of informal sector operations while maintaining practical enforceability. The current regulatory system, primarily designed for formal sector establishments, needs significant adaptation to address the challenges and constraints faced by roadside vulcanizers. This adaptation should include simplified compliance requirements, flexible enforcement approaches, and supportive rather than punitive regulatory strategies. The establishment of specific occupational safety and health standards for roadside vulcanizing operations would provide clear guidelines for hazard control and risk management (House of Representatives, Federal Republic of Nigeria. 2025). These standards should address key areas such as chemical handling, fire safety, personal protective equipment, and workplace design while taking into account the resource constraints and operational realities of informal sector workers. The development of these standards should involve consultation with vulcanizers, their representatives, and other stakeholders to ensure that they are practical and achievable.

Enforcement strategies for informal sector operations require innovative approaches that balance regulatory compliance with support for worker safety and economic viability. Traditional enforcement models based on penalties and work stoppages may be counterproductive for informal sector workers who depend on daily income for survival. Alternative approaches such as educational outreach, voluntary compliance programs, and incentive-based regulations may be more effective for encouraging safety improvements in roadside vulcanizing operations.

The integration of occupational safety and health requirements into business registration, licensing, and permit processes could provide opportunities for reaching informal sector workers with safety information and resources. This integration should include the provision of safety training, access to protective equipment, and ongoing support for compliance with safety requirements. The development of simplified registration processes and reduced bureaucratic barriers could encourage more vulcanizers to operate within the formal regulatory framework.

6.6. Institutional Capacity and Support Systems

The development of institutional capacity for supporting occupational safety and health among roadside vulcanizers requires a multi-faceted approach involving government agencies, professional organizations, educational institutions, and community-based organizations (Segi, Ogoniba and Joy, 2023). The current institutional landscape in Nigeria lacks the specialized expertise, resources, and infrastructure needed to effectively address the occupational safety and health needs of informal sector workers. Building this capacity requires sustained investment in training, equipment, and organizational development (Mandowa, Matsa and Jerie, 2025). The establishment of occupational health services specifically designed for informal sector workers would provide essential support for hazard assessment, health surveillance, and treatment of work-related health problems. These services should be accessible, affordable, and culturally appropriate for the needs of roadside vulcanizers. The integration of occupational health services with existing primary healthcare systems could leverage existing infrastructure while building specialized expertise in work-related health issues.

Training and education programs for safety professionals, healthcare providers, and regulatory officials should include specific modules on informal sector occupational safety and health issues. These programs should address the unique challenges and constraints faced by informal sector workers and provide practical approaches for assessment, intervention, and support. The development of specialized training materials and resources for different stakeholder groups is essential for building effective institutional capacity. The creation of support networks and peer learning opportunities for roadside vulcanizers can facilitate knowledge sharing, collective problem-solving, and mutual support for safety improvements. Professional associations, cooperatives, and community-based organizations can play important roles in organizing these networks and providing platforms for information exchange. The development of mentorship programs, peer education initiatives, and collaborative safety projects can help build a culture of safety within the vulcanizing community.

7. Research Priorities and Knowledge Gaps

The current state of knowledge regarding occupational safety and health among roadside vulcanizers in Nigeria reveals significant research gaps that limit the development of effective prevention and intervention strategies. Comprehensive epidemiological studies are needed to establish the true burden of work-related injuries and illnesses in this population and to identify the most significant risk factors for adverse health outcomes. These studies should include both cross-sectional surveys to assess current health status and longitudinal cohort studies to track the development of chronic diseases over time. Exposure assessment studies using modern monitoring techniques are essential for quantifying the levels of chemical, physical, and biological hazards encountered by roadside vulcanizers. These studies should include personal monitoring for key contaminants, environmental assessments of work areas, and biological monitoring to assess absorbed doses of hazardous substances. The development of exposure-response relationships for priority hazards would provide valuable information for establishing appropriate exposure limits and protective measures.

Intervention research is needed to evaluate the effectiveness of different approaches to hazard control and risk reduction in roadside vulcanizing operations. This research should include assessments of engineering controls, personal protective equipment, training programs, and regulatory interventions to determine which approaches are most effective and practical for this population. The development and evaluation of innovative, low-cost solutions specifically designed for informal sector operations should be a priority research area. Economic studies examining the costs and benefits of safety interventions would provide important information for policy development and resource allocation decisions. These studies should include assessments of the economic burden of work-related injuries and illnesses, the costs of implementing safety measures, and the economic benefits of prevention programs. The development of economic models that account for the informal nature of vulcanizing operations and the limited resources available to workers would be particularly valuable.

8. Conclusions and Recommendations

The review of safety assessment and risk analysis for roadside vulcanizers in Nigeria reveals a complex occupational health challenge that requires multifaceted solutions addressing technical, regulatory, educational, and socioeconomic factors. The informal nature of roadside vulcanizing operations creates unique challenges for traditional occupational safety and health approaches, requiring innovative strategies that balance worker protection with economic viability and practical implementation considerations. The evidence clearly demonstrates that roadside vulcanizers face significant occupational health risks from chemical exposures, physical hazards, ergonomic stresses, and environmental factors. These risks are compounded by limited access to safety information, protective equipment, healthcare services, and regulatory protection. The cumulative impact of these factors creates a situation where workers bear a disproportionate burden of occupational injury and illness without adequate support or protection.

The development of effective solutions requires a coordinated approach involving multiple stakeholders, including government agencies, professional organizations, educational institutions, healthcare providers, and the vulcanizers themselves. This coordination should focus on developing practical, culturally appropriate interventions that address the specific needs and constraints of roadside vulcanizing operations while building the institutional capacity needed for sustained improvement. Priority actions should include the development of adapted safety standards and guidelines, the establishment of training and education programs, the creation of accessible occupational health services, and the implementation of supportive regulatory frameworks. These actions should be supported by ongoing research to evaluate their effectiveness and to identify emerging hazards and intervention opportunities. The protection of roadside vulcanizers' health and safety is not only a moral imperative but also essential for sustaining this vital sector of Nigeria's informal economy.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article

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