American Journal of Applied Sciences and Engineering | *ISSN 2766-7596*
Published by AIR JOURNALS | *https://airjournal.org/ajase*
12011 WestBrae Pkwy, Houston, TX 77031, United States
airjournals@gmail.com; enquiry@airjournal.org

Research Article

Enhancing Agricultural Productivity: The Impact of Safety Management and Human Factors in Smart Farming Systems

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Abstract

This paper explores the critical role of safety management and human factors in enhancing productivity within smart farming systems. With increasing global demand for food production, smart farming has emerged as a key solution by integrating advanced technologies like IoT, robotics, and data analytics. While these technologies offer potential benefits such as cost reduction, improved yields, and better resource management, they also present challenges related to high initial costs, limited digital literacy among farmers, and fluctuating infrastructure support. This study emphasises the importance of aligning safety management with human factors to mitigate risks and optimise operational efficiency. A comprehensive approach that considers both human-centred design and safety protocols is essential for ensuring the success of smart farming systems. The findings suggest incorporating safety management and human factors can lead to sustainable, efficient agricultural practices and foster broader adoption of smart farming technologies.

Keywords	*Agricultural Productivity; Safety Management; Smart Farming Systems; Human Factors; Precision Agriculture; Automation in Farming*
Citation	Muhammed, U. & Adebayo, A. (2024). Enhancing Agricultural Productivity: The Impact of Safety Management and Human Factors in Smart Farming Systems. *American Journal of Applied Sciences and Engineering, 5(4) 1-14.* https://doi.org/10.5281/zenodo.13994874

Volume 5, Number 4 | 2024 | 1-14 | *DOI: https://doi.org/10.5281/zenodo.13994874*

Introduction

In the face of existing and future global challenges, the demand for agricultural productivity is increasing more than ever to meet humanity's food and nutrition needs (Hemathilake & Gunathilake, 2022). It is estimated that agricultural production must increase by 70% by 2050 if it is possible to feed the population (Bahar et al., 2020). This work discusses the safety management approaches and human error probabilities in agricultural practices, mainly in intelligent farming systems. The application of technology to agriculture is not new. For centuries, mankind has sought to increase agricultural yields and crop production through technology. However, during the eighteenth and nineteenth centuries, industrialisation began to have a tangible impact on agrifood, from practices to logistics with the transformation of machinery, tools, and production models, especially with the mechanisation of farming (Davis & White, 2020). Agricultural productivity could soon be based on the interconnected network of equipment led by the new industry. Sensing society, this is increasingly occurring in leisure and for professionals as intelligent farming, often also known as precision farming, digital farming, agriculture 4.0, etc. According to these latitudes, the concept belongs to a working group, where smart farming is considered "production, processing, distribution, and nutrition sectors" (Beltran-Peña et al., 2020). This new generation of integrated farming systems can offer more sustainable agricultural production and economic and environmental performance than current systems through more efficient use of inputs and natural resources. However, production, processing, and logistics subsystems need to be designed as a systemic approach where mistakes, above all in planning and interaction, are less likely. Only in this way can they be considered for transfer to end-users of prototypes and agricultural products not yet fully exploited, like remote mechanised production, mainly in direct interaction between humans.

Smart Farming Systems: An Overview

Smart farming, as seen in Figure 1, refers to the integration of information and communication technologies (ICT) into farm management, enabling automation and optimisation of various agricultural tasks, leading to more efficient and productive operations (Shams et al., 2020). Core components of smart farming include sensor networks that monitor environmental factors such as soil, weather, and livestock health, while advanced data analytics help interpret this data for decision-making, such as optimising planting schedules or monitoring livestock (Rana et al., 2022). Automation and robotics, like autonomous tractors and automatic guidance systems, reduce labour costs and improve efficiency, while wearable sensors for livestock enhance health monitoring and management. Smart resource management allows precise application of water, fertilisers, and crop protection, minimising waste and promoting sustainability. The potential benefits of smart farming include cost reduction, increased yield, improved product quality, efficient resource use, and solutions to labour shortages. However, several challenges hinder widespread adoption, including high initial investment costs, a shortage of skilled labour, unreliable electricity in rural areas, and the need to align technology with human factors for smooth integration (Lakhani et al., 2023). Despite these obstacles, smart farming represents the future of agriculture by offering significant advancements in productivity, sustainability, and resource management, with the potential for broader adoption as technology becomes more accessible.

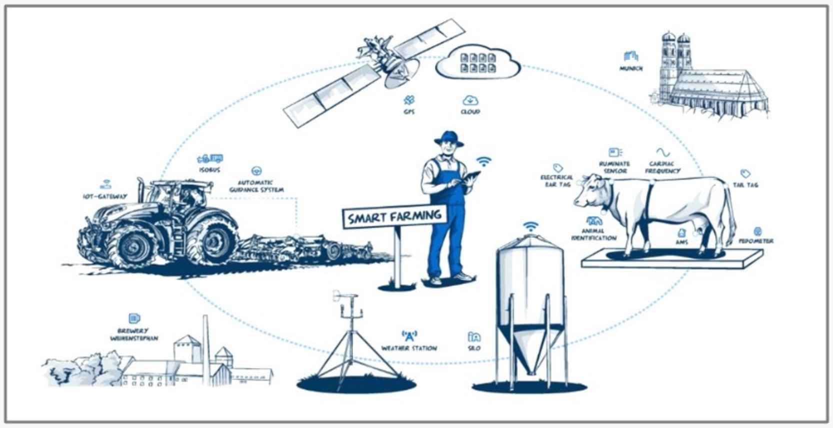

Figure 1: Contents of the new certificate program "Smart Farming and IoT in Agriculture" (Graphic: TUM Institute for Lifelong Learning).

Definition and Components

Smart farming systems optimise management using carefully controlling processes to achieve their goals (Pathak et al., 2020). Equally important in the technological development of smart farming systems are the so-called enabling technologies, like drones and aerial vehicles, sensor technology, field robotics, decision support systems, and predictive analytics (Dutta & Goswami, 2020). Drones, also called unmanned aerial vehicles, are remote-controlled aerial devices that offer great potential for use in agriculture, with applications ranging from planting and spraying crops to managing cattle (Ayamga et al., 2021). Predictive analytics refers to various statistical techniques, from modelling, machine learning, and data mining, which analyse current and historical facts to predict future or otherwise unknown events (Rejeb et al., 2022). Drone technologies are progressively integrated with the current evolution of smart farming by adopting relevant approaches to minimise crop inventory costs, offer improved and advanced farming practices for better crop management and yield, and further improve the sustainable development of connected farm assets. These technologies aim to improve agricultural-related activities, such as accident prevention, monitoring structural damage, increased production, and real-time territorial mapping. State-of-the-art technology can monitor crop yield conditions through early crop yield measurement and monitor the overall performance of a farm in a more cost-effective manner than traditional methods, as well as enable adequate machine deployment across field monitoring. Access to agricultural data from assets can provide benefits such as labour cost savings, improved livestock management, and cost reductions in managing and maintaining crops and equipment. To realise the features above and take advantage of the emerging digital markets, broad and reliable coverage and a solid and intelligent connectivity infrastructure are required to deploy UAV technology in rural areas.

Benefits and Challenges

Today's smart farming systems have the potential to increase agricultural productivity by better feeding and protecting growing crops and by breeding healthy farm animals (Javaid et al., 2022). They assist farmers in making optimal decisions regarding using their resources based on comprehensive data, fostering an economically and ecologically sustainable approach to agricultural management (Sharma et al., 2022). Moreover, purchasing modern agricultural equipment for precision farming is associated with long-term financial benefits. In this context, smart farming can contribute to farm sustainability and profitability by adopting new technology. Following this idea, there are first indications that the quality of some agricultural products is increased by the technological improvement of productive processes (Karunathilake et al., 2023).

Implementing smart farming technologies and devices toward optimising the primary food production value chain is linked to specific positive effects and is characterised by numerous challenges. For instance, smart farming hardware and software solutions were found to determine clear performance increases. However, other parameters linked to farmers or operators and unexpected technological problems were identified as possible obstacles to implementing innovative farming systems (Lytos et al., 2020). Regarding societal acceptance, gender, education, and a broad spectrum of societal topics, including policy and citizen engagement, were found to reduce individual expectations in intelligent farming systems. Moreover, a lack of ICT and digital competencies from the farmers' and operators' perspectives was recognised as a barrier to sustainably and profitably integrating smart farming into their businesses. Social acceptance of intelligent farming is a crucial issue for promoting digitalisation mechanisms. Table 1 summarises the benefits and challenges of intelligent farming systems, along with examples and references:

Table 1: Benefits and Challenges of Intelligent Farming Systems

Category	Benefits	Challenges	Examples	References
Agricultural Productivity	Increased productivity through optimal feeding and protection of crops and animals.	High initial costs of modern equipment and technological infrastructure.	Innovative farming systems like automated irrigation and pest management can boost crop yields.	(Javaid et al., 2022)
Resource Management	It helps farmers make data-driven decisions, optimising resources such as water and fertilisers.	Lack of access to innovative technologies due to high costs or geographical constraints in rural areas.	Sensors and data analytics for precision irrigation help conserve water while maximising crop health.	(Sharma et al., 2022)
Farm Sustainability	Contributes to sustainability by minimising input waste and increasing efficiency.	Limited digital literacy among farmers hinders technology adoption.	Reduced use of pesticides through targeted spraying using drones reduces environmental impact and promotes sustainability.	(Sharma et al., 2022; Lytos et al., 2020)
Profitability	Long-term financial benefits through higher yields, better quality products, and reduced waste.	Short-term financial burden due to the cost of purchasing and maintaining modern agricultural machinery.	Precision farming equipment like GPS-guided tractors can optimise planting patterns and reduce fuel consumption, saving costs.	(Karunathilake et al., 2023)
Product Quality	Improved quality of agricultural products through technological advancements.	Difficulty in aligning the technology with local farming practices and knowledge, leading to inefficiencies.	Innovative farming tools such as remote sensing technologies can monitor crop health, yielding higher-quality yields.	(Karunathilake et al., 2023)
Operational Efficiency	Automation reduces manual labour, making farming operations more efficient and less time-consuming.	Technological issues include system malfunctions, lack of reliable power, and internet in rural areas.	Robotics and autonomous tractors help with planting, harvesting, and other repetitive tasks, reducing the labour burden.	(Lytos et al., 2020)
Societal Acceptance	Encourages modernised farming, attracting younger generations to agriculture.	Societal acceptance issues due to gender, education, and policy concerns.	Younger farmers may be more inclined to adopt intelligent farming technologies, while older generations may resist digital transformation.	(Lytos et al., 2020; Sharma et al., 2022)
Technology Integration	Data integration helps with real-time monitoring and decision-making.	Lack of ICT and digital skills among farmers limits the adoption and success of innovative farming technologies.	Integrating smart sensors and mobile apps for farm management can provide real-time updates on soil conditions and crop health, optimising yield.	(Lytos et al., 2020; Javaid et al., 2022)

This table balances the positive impacts smart farming can have on productivity, resource management, and sustainability while highlighting the technological, financial, and societal challenges that can hinder its broader adoption.

Safety Management in Agriculture

Safety management is essential in agricultural practices; however, this aspect is often neglected worldwide and generally directed to other industrial sectors (Benos et al., 2020). Basic requirements for adequate agricultural practices include legal standards related to ensuring food safety, guarantees of good agricultural practice, respect for the environment, and, most importantly, the implementation of the principles of safety and health at work by taking into account the specificity of the agricultural sector (Rizzo et al., 2021). Since all agricultural operators are legally responsible for implementing these requirements, such as preventing accidents, the voluntary or enforced increase in safety and health management principles will be essential to enhance agricultural activities, especially smart farming. Therefore, the paper presents modern safety management frameworks and approaches to managing human factors, which can be adapted to smart farming systems.

Safety management uses systematic tools or methodologies to identify and reduce risks—whether technical, economic, ecological, or agricultural—and is an active means to prevent the emergence of major accidents (Deguine et al., 2021). In practice, due to the high proportion of the human factor in the emergence of agricultural accidents and catastrophic events, regulations and standards have been developed that, like the principles of safety management itself, make it easier for employers, employees, and services responsible for safe working conditions to implement them in agriculture. Safety management is focused on the precautionary approach, i.e., preventing accidents or illness at work due to creating stressful or unhealthy working conditions; as part of standards and directives for introducing globally accepted social responsibility, modern quality and safety management is moving to a new sphere defined as excellence practice. The paper aims to analyse the importance of safety management and land technological systems, including human factors, for agricultural activities and develop practical guidance specifically adapted for intelligent farming systems.

Importance of Safety Management

The development and implementation of safety measures in agriculture offer numerous benefits to farm workers, such as preventing work-related accidents and occupational diseases, and significantly contribute to increasing productivity. These measures extend the useful lifespan of machinery and infrastructure by integrating improvements in technology and modern infrastructure (Sekaran et al., 2021). Production systems must account for potential farm patterns, resources, climate inputs, and management's commitment to safety significance and productivity factors. Therefore, safety management is an essential component of efficient agricultural operation. As the saying goes, prevention is better than cure, and it is crucial to prevent accidents and protect workers against farm machinery and equipment hazards (Selim, 2020).

Employers are responsible for providing a safe and healthy working environment, free from recognised hazards that may cause their employees severe physical harm or death. In addition, enforcing laws, rules, or regulations that impose obligations for safe working conditions is essential. This should be a collaborative effort between management and workers. Preventing and controlling work-related hazards directly and indirectly affect the economy. The direct costs include employer compensation and medical expenses, while indirect costs, such as reduced morale and productivity, impact operations. Therefore, safety management should be incorporated into all agricultural projects through integrated activities, roles, programs, structures, and objectives (Wang, 2022). Ensuring a safe working environment helps workers return home safely, and several studies suggest that a safe workplace can lead to increased productivity. An unsafe workplace, on the other hand, can lower yields and decrease efficiency (Zhang et al., 2020). A healthy organisation is more efficient, less costly, and better at attracting and retaining both investors and employees.

Safety management has become a priority in many industries, particularly manufacturing, and is now gaining attention in agriculture. Research indicates that integrating safety management into project management concepts, such as zero tolerance and risk reduction, has a positive impact. Studies have shown that half of the near-miss incidents reported by non-technical staff involved machinery, vehicle-related activities, or handling livestock. In contrast, many technical staff near-misses were related to machinery and tractors (Cenolli et al., 2023). Preventing costly injuries is critical to reducing financial risks for employers, decreasing insurance premiums, and minimising associated expenses. Additionally, it boosts employee morale by demonstrating that management cares about their well-being, reducing hiring and training replacement costs. Furthermore, safety management can become a selling point for prospective employees, customers, and patrons, mainly when a business uses higher-quality, safer, and more efficient equipment than competitors offering less expensive alternatives. This emphasis on safety helps build a strong foundation for why safety management is critical in agriculture. In smart agriculture, the increasing availability, sophistication, and diversity of autonomous and intelligent systems require a robust approach to safety. Both passive and active safety measures are essential, as safety is a multidimensional concept that extends beyond human injury (Rizzo et al., 2021). Effective safety management will reduce risks and foster sustainable growth in modern agriculture.

Key Elements of Safety Management

Having elaborated on the dangers of the farm, it becomes necessary to address the principal components of an effective safety management system in agriculture, which can be employed in preventing harmful incidents such as those presented earlier. Safety management encompasses all activities geared towards minimising hazards on farms and involves the ongoing identification and minimisation of risks (Benos et al., 2020). The components of safety management include tools for identifying risk, training farmers and their families, workers, and contractors in safety, communication as a specific risk management process, and providing adequate equipment as part of response capacity (Misra et al., 2022). An essential dimension of comprehensive safety management is emergency preparedness, as discussed below.

Risk assessment, safety training, supervision, monitoring, and enforcement: Regular and systematic risk assessment and management are necessary to optimise farm safety. Safety policies and procedures are important and provide a systematic and consistent approach to risk management. Procedures need to be supported by training and education programs (Okpala & Korzeniowska, 2023). A simple training program for workers need not be onerous; if properly prepared and communicated, it should help minimise their risk of injury. Supervision and enforcing procedures are seen as essential tools and play a crucial role in ensuring safety. For example, regular inspections and repairing or maintaining equipment are important to ensure that hazards are minimised or removed. Finally, equipment, tools, and facilities must be appropriate for the task and in good working condition. Technology and personal protective equipment may also create a safe work environment. However, some of these tools may not be accessible or represent health or safety hazards in other forms. Regardless, addressing the multiple dimensions of farm safety and including all relevant stakeholders is helpful rather than approaching safety as an obstacle to work that should be eliminated (Lee et al., 2021).

Injury prevention is a complex and multidisciplinary scientific field aiming to investigate, design, and develop technically advanced and workable safety solutions and strategies. In other words, injury prevention requires a combination of preventive strategies, including new equipment or engineering solutions, education of personnel in terms of hazards and appropriate responses, organisational changes, legislation and enforcement, and sometimes also personal protective equipment in order to reduce or control exposure (Misra et al., 2022). Combining these strategies to achieve the best results is a topic of ongoing scientific debate. There is potential for embedding an injury expert within a farming expert team or vice versa. The fusion approach could lead to interdisciplinary research and developing multidisciplinary and potentially effective prevention strategies. An injury prevention approach towards farm safety would help reduce incidents and improve farm profitability. Promoting safety in agriculture is expected to contribute to farm sustainability and support smart farming and the rural economy more broadly. Therefore, when discussing food productivity in smart farming, it would be wise to explore agriculture that promotes safety and possibly overall farm sustainability (Benos et al., 2020). When discussing the economics of farming, it would also be wise to consider the farming style that supports the overall content of the farm—not only food and environmental productivity but also utilisation of ergonomically safe production, including the free or almost free but motivated movement of the workforce on the farm at 100% potential. Farm safety is indeed a multifaceted problem.

The key elements of safety management in agriculture involve a range of interconnected components, each designed to minimise risks and hazards, promoting a safer working environment on farms. Based on the studies by Benos et al. (2020), Misra et al. (2022), and other scholars, the following elements are essential to an effective agricultural safety management system:

1. Risk Assessment: The foundation of farm safety begins with regular and systematic risk identification. This process includes evaluating all potential hazards associated with farm activities, ranging from machinery and equipment to environmental conditions. Risk assessments enable the identification of the likelihood and severity of incidents, allowing for targeted risk mitigation strategies (Okpala & Korzeniowska, 2023).

2. Safety Policies and Procedures: Safety policies provide a structured approach to farm safety, ensuring consistency in risk management practices. These policies must be clear, comprehensive, and aligned with

regulatory standards. They guide the implementation of best practices across various farm activities, from handling hazardous substances to operating heavy machinery (Lee et al., 2021).

3. Training and Education: Safety training is critical in ensuring that all individuals working on the farm—whether farmers, workers, contractors, or family members—are adequately prepared to manage risks. If well-designed and communicated, education programs help reduce the likelihood of injuries by teaching safe work practices, emergency response techniques, and hazard awareness (Okpala & Korzeniowska, 2023). Training must also evolve to incorporate technological advancements, addressing new risks posed by modern equipment and processes (Misra et al., 2022).

4. Supervision and Monitoring: Ongoing supervision is essential for ensuring compliance with safety protocols. Supervisors are key in monitoring safety practices, conducting inspections, and ensuring equipment is maintained correctly. Regular inspections and proactive maintenance prevent accidents caused by faulty equipment or unsafe working conditions. Enforcement of safety protocols, including penalties for non-compliance, reinforces a culture of safety (Lee et al., 2021).

5. Emergency Preparedness: Preparedness for emergencies such as accidents, fires, or chemical spills is a critical dimension of safety management. Emergency preparedness plans, including clear communication channels and designated roles, ensure swift responses to mitigate damage and harm. This includes ensuring that emergency equipment, such as fire extinguishers and first aid kits, is available and functional (Misra et al., 2022).

6. Provision of Appropriate Equipment and Facilities: Providing workers with suitable tools and equipment in good working condition is essential to safety. This includes technology and personal protective equipment (PPE), which can significantly reduce exposure to hazards. However, it is essential to acknowledge that some equipment may not always be accessible to all farmers, particularly in less developed regions, or may introduce new risks if not properly used (Benos et al., 2020).

7. Injury Prevention Strategies: Injury prevention requires a holistic approach, combining engineering solutions, safety education, organisational changes, and legislation enforcement. This multidimensional strategy ensures that all potential injury causes are addressed through better-designed equipment, improved safety policies, or protective gear. Embedding injury prevention within broader farm management practices supports farm safety and profitability (Misra et al., 2022).

8. Stakeholder Involvement: An inclusive safety management system involves all stakeholders—farmers, workers, safety experts, and external bodies like regulatory agencies. Engaging these groups in safety discussions ensures that all perspectives are considered and safety measures are practical and effective. Viewing safety as an integral part of farm operations rather than an obstacle fosters a proactive safety culture (Lee et al., 2021).

9. Technology and Smart Farming Integration: Integrating technology into farming practices, such as smart farming tools, can enhance safety by reducing manual labour and exposure to hazardous tasks. Technology can also monitor farm conditions, predict potential risks, and enhance response capabilities. Thus, Smart farming tools contribute to increased productivity and improved safety (Benos et al., 2020).

An effective agricultural safety management system considers the diverse nature of farm work, anticipates risks, and provides practical solutions tailored to specific farm environments. By incorporating these elements, farm safety can be improved, reducing the likelihood of harmful incidents and contributing to the long-term sustainability and economic viability of farming.

Human Factors in Smart Farming Systems

The guiding idea of studies relying on human factors focuses on the human as part of the system. Understanding human behaviour, cognitive processes, and perception can lead to the design of better interfaces and the enhancement of user experience (Wróbel, 2021). In the context of intelligent farming, machines, smart objects, robots, and systems around farmers are "tools" or "intermediaries." The main concerns regarding human-centeredness are based on farmers' characteristics and how these technologies interact with them. Considering human factors is crucial for the proper development of agricultural technologies. Humans are vulnerable to limiting conditions such as fatigue, illness, or distractions, leading to mistakes in routine and complex tasks. During the creation of hazards, human cognitive shortcomings often lead to errors that may result in accidents, ranging from near-misses to severe incidents (Amalberti & Wioland, 2020). There is a significant body of work on human factors analysis in industrial settings, but specific studies focused on innovative farming operation systems are rare (Read et al., 2021). This gap makes system reviews critical, especially where the interaction between living systems (humans) and non-living systems (machines, robots, tractors, drones, etc.) is central to agricultural processes. Research shows that at least 70% of accidents and incidents are due to human error, emphasising the need for designing systems that better support human operators (Bucsuházy et al., 2020). Since the beginning of the industrial era, the most common work-related accidents and ergonomic issues have often been attributed to the human-machine interface. Therefore, ergonomics is essential for creating a safer and healthier work environment.

The advantages of ergonomics and a human-centred design approach include safer system designs that reduce human error and the likelihood of accidents. Involving workers in the design process can ensure system compatibility, which is especially crucial when designing the technology interface in agriculture. User acceptance is a significant factor influencing the functionality and efficiency of many agricultural technologies. Thus, it may be necessary to develop training and educational programs focusing on human-centred design, risk management, and safety instructions that align with the agricultural environment's cultural, social, and political context. However, it is essential to note that as agricultural work becomes more complex, the costs associated with testing new applications and conducting adequate training will increase. Involving users—farmers and workers—in the research and development of agricultural technology and ensuring that systems are designed with the human operator in mind should not be underestimated. This approach will likely contribute to safer and more effective intelligent farming systems.

Understanding Human Factors

Human beings' natural variability and adaptability, known as human factors, play an essential role in enabling a task to be accomplished effectively and safely. Developers can create more efficient and safe work environments by designing technologies to match the characteristics of those who use them (Karwowski & Zhang, 2021). These principles leverage scientific knowledge from psychology and ergonomics to improve computer systems, mobile devices, and software design. Various factors can lead to variability in a person's response to a work environment, including control over themselves and their surroundings, incentives, skill level, tolerance for errors, and external influences such as training and practice (Zarei et al., 2021). In the design of robotic systems, maintaining awareness of these principles can ensure that operators retain a meaningful level of "control" when supervising and interacting with these systems. Unique factors specific to agricultural operations must be considered when designing intelligent farm systems. For instance, decision-making processes can be influenced by a farmer's cognitive and emotional state, their level of knowledge and experience, and how choices are framed. Motivating farmers to adopt and adapt existing and future intelligent farming tools depends on how these tools are perceived, the perceived risks, and whether the perceived benefits are valuable (Shneiderman, 2020).

Despite the human capacity for problem-solving and learning, users have a limited working memory and attention span, which affects their situational awareness of current activities and conditions around them. Developers can improve user interfaces by adhering to good user experience design principles, including introducing strong feedback loops and usability testing methodologies to flag potential design issues early on (Pollini et al., 2022). These techniques ensure that innovative farm systems better suit farmers' interaction needs. Several methods, such as observational studies, surveys, interviews, remote testing, walk-through testing, and cognitive task analysis, can help visualise user characteristics and identify potential system weaknesses. Studies have demonstrated that human factor-informed design promotes systems that are both accessible and technically powerful, leading to increased adoption of technology and fueling both productivity and innovation in the long term.

Factors Affecting Human Performance

Enhancing people's performance is a core aspect of Human Factors (HF) management. Several factors can affect human performance, including physical, psychological, and environmental considerations. The physical factor refers to ergonomic aspects and the potential development of fatigue or health issues in humans. The psychological factor encompasses mental conditions during work, including stress levels and workload indices. The environmental factor refers to external conditions such as weather, workplace layout, and more. In addition, human resource factors, such as people's qualifications and adaptability to jobs, are also critical. It is essential to reconsider these factors comprehensively because performance is complex and cannot be investigated solely from a physical, psychological, or environmental perspective (Atmaja et al., 2022). Table 2 summarises the factors that affect human performance in Human Factors (HF) management:

Table 2: Factors that affect human performance in Human Factors (HF) management

Factor	Description	Examples	References
Physical Factors	Ergonomic aspects, potential development of fatigue, and health issues affecting workers.	Poorly designed workstations may lead to back pain, fatigue, or repetitive strain injuries.	(Atmaja et al., 2022)
Psychological Factors	Mental conditions during work, including stress levels, workload indices, and cognitive demands.	High-stress levels due to workload pressures can reduce decision-making accuracy and overall performance.	(Atmaja et al., 2022)
Environmental Factors	External conditions such as weather, workplace layout, noise, and lighting affect performance.	Extreme weather conditions or poor workplace lighting can reduce focus, increasing the likelihood of errors and accidents.	(Atmaja et al., 2022)
Human Resource Factors	Workers' qualifications, skills, adaptability, and fit for specific job roles.	A worker with inadequate training or adaptability may struggle to perform tasks efficiently, increasing the risk of errors.	(Atmaja et al., 2022)
Comprehensive Approach	Performance is influenced by physical, psychological, and environmental factors, which must be addressed together.	A comprehensive assessment should consider all factors to improve worker well-being and operational efficiency rather than focusing on one area.	(Atmaja et al., 2022)

This table highlights the key factors influencing human performance in work environments, emphasising the need for a comprehensive approach to Human Factors management to address the complexity of these interrelated elements. The comfort of the workplace and operations largely depends on the ergonomics of the devices and facilities. When evaluating intelligent farming technology, it is generally believed that operations will not present significant challenges; however, daily workload experiences might offer different insights. To achieve optimal working conditions, a facility-equipped transformable vehicle has been developed as one solution. Numerous studies have explored the management of agricultural machinery. Work-related health issues, such as back problems, hearing loss, or skin cancer due to prolonged exposure to sunlight, are common concerns in agriculture (Velasco-Muñoz et al., 2021). Human performance is directly linked to the economic performance of agricultural management. Applying Human Factors and Human-Machine Systems (HFHMS) can ultimately simplify innovative farming systems' safety and health management, contributing to the development and competitiveness of innovative farming practices. Numerous human and environmental factors easily influence human performance. Moreover, using robotics in agriculture shows promise in relieving farmers from physically demanding and hazardous field activities, further enhancing productivity and safety (Durham & Mizik, 2021).

The Interplay of Safety Management and Human Factors in Smart Farming Systems

Safety management has evolved to consider human abilities and limitations alongside more traditional approaches. Better safety and operational performance can be achieved when safety management and human factors are aligned. For example, when safety management strategies help reduce the cognitive load on operators or provide a coherent framework for performing tasks, operators feel more in control of the situation. This leads to a greater willingness to engage with safety procedures and use their benefits (Yazdi et al., 2020). However, there are instances where safety expectations and human factors must be managed carefully. What is safe is not always efficient, often described as the 'efficiency-thoroughness trade-off.' This term characterises the tension that arises when making decisions that involve balancing risk and time-critical tasks. According to this principle, some integrated safety modes can enhance systems' operational effectiveness, even when the safety barriers are not entirely impermeable (Hendrycks et al., 2021). One area where this trade-off is particularly evident is in intelligent farming. Safety rules at the technical level can profoundly impact operations, financial margins, and human lives. To adopt a comprehensive perspective, fully understanding the cognitive work involved in intelligent agricultural systems is essential. Proactive safety management principles that integrate the needs of human factors must be advocated. Additionally, implementing a robust feedback mechanism is crucial to reduce significant gaps caused by relying solely on typical safety components without accounting for human factors.

Synergies and Conflicts

In work domains characterised by extensive socio-technical interdependencies, both synergies and conflicts may exist between safety management and human factors in enhancing productivity. For example, some safety regulations may motivate workers to improve their performance by involving them in decision-making or encouraging closer collaboration. Additionally, complementary safety practices to increase workers' awareness of their jobs and environment can lead to more efficient and safer performance, fostering worker satisfaction and longer employment rates (Nkrumah et al., 2021). Similarly, well-implemented safety systems can positively impact the well-being and motivation of workers. Research has shown that emphasising safety in organisations with high automation increases workers' safety motivation, enhancing effectiveness and efficiency (Lu et al., 2020). Thus, it does not necessarily follow that concerns in the work system will result in conflicts; the same safety measure can simultaneously have positive and negative impacts. By distinguishing these relationships, guidelines can be developed to promote aspects with the highest efficiency, tailored to specific work domains (Bolis et al., 2020).

In contrast, implementing overly strict safety regulations or imposing constraints that do not align with workers' internal knowledge of the working environment and their skills can lead to workarounds and cause workers to disregard safety regulations. This divergence between formal organisational expectations and the absolute need for uninterrupted operations can have a profoundly negative impact. The more rigid and restrictive safety regulations become, the more frustrated and fatigued workers will feel, which increases the likelihood of mistakes and incidents (Nnaji et al., 2020).

A key consideration in smart farming systems is finding the right balance between formal safety regulations and leveraging human factors to maintain flexibility and operational continuity while ensuring worker safety. This requires a holistic perspective that addresses interdependencies, beginning with the early shaping of missions and extending to the final delivery of goods. Guidelines should focus on creating integrative strategies that account for coherence and complementarity between safety management and human factors to achieve a balance that ensures safety and productivity.

Conclusion and Future Directions

In this review, human factors and safety management in innovative farming systems have been investigated to understand better how to enhance productivity while minimising safety threats. It is becoming increasingly evident that digital technologies in agriculture can strengthen the industry, albeit not without their weaknesses. Although digital agriculture can make quicker or better decisions, increasing resource use and reducing production risks through an engagement approach, the extra agricultural human factor increases the importance of safety and safety protocols. Effectively, it is not valid to ignore the elements of safety while enhancing agricultural efficiency. Addressing the human factor regarding technical, mental, and physical safety is crucial to ensure that they contribute to this novel case of agriculture without fear.

We conclude from our review that the following holistic approaches must be managed for safe agricultural management in smart farming systems. When devising a technological strategy, the overall approach of integrating a human factor as a maximum priority has been overlooked because of the potentially significant and direct consequences of errors and control. The study of human capital should not be limited to farmers, operators, or managers. Future work is necessary to manage the role of consultants and industry stakeholders. This might help the development of tailored learning and education paths and approaches aimed at developing appropriate skills. Furthermore, because some applications that reduce the need for dedicated labour would free up time, attention, and resources for other economic activities near agriculture, we could also consider looking at other kinds of automation, which are still at their early stages in general in agriculture. Whether firm chair administrators utilise smartphone applications for business management decisions should also be evaluated. It is assumed that farm chairs' higher managerial skills are less time-consuming. However, available evidence on how farm managers' adoption of practical smartphone applications enhances dual-impact productivity is limited. To enhance labour productivity, integrated training programs that result from labour-saving technology capabilities must be developed. To evaluate the effective use of input and its impact on economic and technological methods, further study is needed to use detailed farm-level input utilisation information in agriculture. The emergence of smartphones and other modern technologies has made it easier to do significantly intricate work. As a determining factor for the impact per unit of input, the result suggests that smartphone capability could serve in the estimation of analysis model input; several hypotheses are supported, and follow-up research should focus on incorporating these results into the farm-level analysis based on smartphone capabilities of the management.

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