Smart Information Systems for Retort Process Optimisation in Malaysian SMEs: A Literature-Based Review of Food Safety and Traceability

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ABSTRACT

Malaysian Small and Medium-sized Enterprises (SMEs) operating in the food processing sector, particularly those utilising retort technology, face significant challenges in optimising their processes, ensuring stringent food safety standards, and maintaining comprehensive product traceability. Limited resources, technical expertise, and access to advanced technologies often exacerbate these challenges. This article presents a comprehensive literature-based review exploring the potential of Smart Information Systems (SIS) to address these critical issues within the context of Malaysian SMEs. The study synthesises findings from existing academic literature on SIS, retort process optimisation, food safety management, and traceability in the food industry, with a specific focus on the Malaysian SME landscape. Employing a desktop analysis methodology, this review systematically examines peer-reviewed articles, conference papers, and industry reports to identify key themes, technological applications, and conceptual linkages. The analysis reveals that SIS, leveraging technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data Analytics, can significantly enhance retort process control through real-time monitoring and predictive analytics.

Furthermore, SIS can bolster food safety by automating critical control point monitoring and facilitating proactive risk assessment. Crucially, these systems can revolutionise traceability by integrating data across the supply chain, enabling immutable record-keeping through technologies like blockchain, and improving recall management. The paper discusses the specific challenges faced by Malaysian SMEs in adopting SIS, including high initial investment and lack of technical expertise, alongside potential enablers such as government support and collaborative initiatives. The findings underscore the strategic imperative for Malaysian SMEs to embrace SIS for improved operational efficiency, enhanced food safety compliance, and robust traceability, ultimately contributing to their competitiveness and market access. Recommendations for industry practitioners, policymakers, and future research directions are provided to guide the successful implementation and further exploration of SIS in this vital sector.

Keywords— Smart Information Systems, Retort Process Optimisation, Malaysian SMEs, Food Safety, Traceability, Food Industry.

INTRODUCTION

The food processing industry plays a pivotal role in the global economy, contributing significantly to national GDPs, employment, and food security. In Malaysia, Small and Medium-sized Enterprises (SMEs) form the backbone of this industry, driving innovation, providing local employment, and catering to both domestic and international markets, particularly within the Halal food sector (Nor et al. 2016). These SMEs are crucial for the country's economic development and its position as a key player in the global food supply chain.

Within the food processing landscape, retort technology is a cornerstone for producing shelf-stable food products, ensuring their microbiological safety and extending their shelf-life without refrigeration (Jimenez et

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al. 2024). This thermal preservation method involves subjecting packaged food to high temperatures and pressures to destroy spoilage microorganisms and pathogens. While highly effective, retort processing is characterised by complex operational parameters, high energy consumption, and the critical need for precise control to prevent over-processing, which degrades quality or under-processing, which poses severe food safety risks (Zhu et al. 2022). The inherent variability in raw materials, equipment performance, and human factors further complicates achieving optimal processing outcomes.

In recent years, the global food industry has witnessed an escalating demand for enhanced food safety and comprehensive product traceability. Consumers, regulators, and supply chain partners increasingly require transparency regarding the origin, processing, and handling of food products (Qian et al. 2022). This demand is driven by concerns over foodborne illnesses, food fraud, and the desire for sustainable and ethically sourced products. For Malaysian SMEs, complying with these stringent international and domestic food safety regulations such as Hazard Analysis and Critical Control Points (HACCP) and ISO 22000 (International Organization for Standardization – Food Safety Management System (FSMS)) and establishing robust traceability systems presents a significant challenge, often due to limited financial resources, technical expertise, and access to advanced technological infrastructure (Talib et al. 2014).

The SMEs rely on manual, fragmented and reactive process monitoring, quality control and record-keeping in many SMEs. This may cause inefficiency, slow response to quality deviations and product tracing in cases of massive recall. The emergence of Industry 4.0 technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics, and Machine Learning, can change the food processing industry forever. All of these technologies are the foundation of Smart Information Systems (SIS) that may generate real-time insights, predictive analytics, and automated decision support (Magableh et al. 2024).

Although the benefits are apparent, the lack of extensive literature focusing on the application and implications of Smart Information Systems to retort process optimisation, food safety enhancement, and tracing improvement of the Malaysian SMEs is significant. Although some of these areas have been reviewed separately, a comprehensive review, which incorporates these important aspects in the context of the Malaysian SME environment, has been lacking. The knowledge of this nexus is important to enable Malaysian food SMEs to address operational challenges, regulatory compliance, and competitiveness in both local and international markets.

This article will attempt to address this gap in the research by focusing on a comprehensive literature-based review prompted by the central research question of how Smart Information Systems can be used in retort process optimisation, improving food safety, and enhancing traceability in Malaysian Small and Medium-sized Enterprises. This paper aims to establish a conceptual explanation of the synergetic nature of SIS transformation of retort operations in the context of the available knowledge in academia and industry.

METHODOLOGY

In this research paper, a desktop analysis methodology, namely a critical literature-based review, has been used to explore the possibilities of Smart Information Systems (SIS) optimisation of the retort processes, defence of the food safety, and improvement of the traceability in the context of the Malaysian Small and Medium-sized Enterprises (SMEs). This approach is highly appropriate for synthesizing existing information and understanding a complex, interdisciplinary subject without requiring primary data collection.

The study design described is qualitative and systematic, with the emphasis on an in-depth consideration of available academic and industry literature. Peer-reviewed articles, conference papers, academic books, and well-realised reports of the industry are used as the primary sources of the analysis. These sources were selected based on their value as primary sources relevant to the main research areas of Smart Information Systems, optimisation of the retort process, food safety within food processing, traceability within the food supply chain and the context of Malaysian SMEs within the food industry.

A stringent data extraction and synthesis process was completed on finding suitable literature. This required reading and analysing the information on each of the documents selected systematically to identify the relevant

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information.

An analysis was done through a thematic synthesis of the literature obtained. This methodology made it possible to identify the repeated concepts, establish the relations between the SIS capabilities and retort process outcomes, and develop a conceptual framework. This framework pictures the possibilities of adopting SIS and resulting in improved optimisation of the retort process, food safety compliance, and strong traceability in the context of the Malaysian SMEs in a special case. This study exclusively refines and synthesizes existing knowledge from prior literature, forming a solid basis for future theoretical development and empirical research.

LITERATURE REVIEW

Smart Information Systems (SIS) in Food Processing

Smart Information Systems (SIS) constitute a paradigm shift to the traditional information systems scenario. They are characterised by the combination of sophisticated technologies to reduce the need for intelligent, adaptive and proactive support of decision-making and operational processes. In VPS, in their essence, SIS are based on the intersection of multiple crucial technological innovations, such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics, and Machine Learning (ML) (Magableh et al. 2024). With this integration, large amounts of data can be captured, processed and analysed in real-time, and raw data can be interpreted into compelling insights.

SIS can be best tracked back to simple Management Information Systems (MIS) and Decision Support Systems (DSS), which gave way to more evolved intelligent systems that can learn and adjust to their environment. The term modern SIS is defined by the capacity to sense, analyse and respond to dynamic environments and often with minimal human intervention. They aim to increase efficiency, optimise resources, improve performance, and ease compliance in numerous industries (Im et al., 2018).

In the context of food processing, an SIS is composed of several interconnected elements that work in concert to enhance efficiency, safety, and quality. The sensor and IoT field constitute the foundation of the system by obtaining real-time data related to various steps in the production process, such as temperature, humidity, pressure, pH level, equipment status, and product quality indicators. Particularly in the case of retort processing, such IoT sensors can measure the chamber parameters, core temperatures of the products and even equipment vibrations (Khamaludin, 2023). The vast amount of data generated needs an efficient structure to store and manage the data, which is accomplished by cloud computing and data platforms. The benefit of big data management has gone beyond scalable and flexible processing using cloud-based systems, which also enables accessibility and collaborations across various stakeholders (Jagtap, 2021). The connection speed, i.e., 5G and Wi-Fi, is used to provide high-speed connectivity to maintain data flow and keep it uninterrupted, which minimises latency and facilitates real-time monitoring (Dhal & Kar, 2025).

Artificial intelligence (AI) and machine learning algorithms are on top of this infrastructure and serve as the analytical engine of SIS. The use of these technologies enables the processing of complex data, identifying patterns, anticipating possible problems, including equipment failure or changes in product quality and process parameters, and optimising processes. Machine learning models learn the results over time to improve their performance through the learning of historical data through predictive maintenance, energy optimisation, and better decision-making (Dhal & Kar, 2025). Accompanying this is enhanced data analytics and visualisation, which can turn the raw data into an actionable insight through interactive dashboards. Using these tools, managers and operators can track key performance indicators (KPIs), identify patterns, and make timely decisions (Geminarqi and Purnomo, 2023). Lastly, SIS also provides the final linkage between digital and physical operations by having actuators and automation systems. The components perform autonomous settings like temperature control of retorts, altering the processing time, sending out maintenance alerts and so on, ensuring that the results of analytics are genuinely reflected in the developments in operations (Simpson et al., 2007).

The usefulness of employing SIS in the food industry is prismatic. They allow the real-time control of the production lines, and in turn, anomalies and deviations are identified on the spot. Predictive analytics features

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enable proactive action, which stops equipment failure, reduces waste, and maximises resources. SIS may also help provide high-level decision support on more complicated operational tasks, like optimising production scheduling or logistics management of the supply chain. Besides, automation of data collection and analysis in SIS decreases manual reporting errors, enhances the accuracy of data, and improves the efficiency of reporting procedures, making regulatory compliance and certification essential (Ihueze, 2018).

SIS are used in several areas across the wider food industry. They improve supply chain management transparency and efficiency by increasing farm-to-fork transparency. SIS also permits real-time monitoring of product characteristics and environmental quality, hence quality and safety. They provide proficiencies in energy management that entail identifying inefficiencies and recommending change. The use of SIS is widespread, but its particular implementation and its effect on other important processes, such as retort sterilisation, particularly in SMEs, should be investigated further. Table 1 summarizes the core technologies of SIS and their specific impacts on the food processing sector:

Technology	Impact on Retort Process Optimization	Impact on Food Safety	Impact on Traceability
Internet of Things (IoT) Sensors	Real-time monitoring of temperature, pressure, pH, equipment status, product core temperature. Predictive maintenance.	Continuous monitoring of Critical Control Points (CCPs). Early detection of deviations. Reduced human error.	Automated data capture from production line. Immutable records. Enhanced recall management.
Artificial Intelligence (AI) & Machine Learning (ML)	Predictive analytics for optimal processing parameters. Adaptive control to prevent over/under-processing. Energy optimization.	Proactive risk assessment. Anomaly detection in quality data. Predictive identification of potential contamination.	Pattern recognition in supply chain data. Automated data reconciliation. Improved data integrity.
Big Data Analytics	Processing and analysis of vast datasets for process insights. Identification of hidden patterns and correlations.	Comprehensive data analysis for risk identification. Trend analysis for foodborne illness prevention.	Integration of disparate data sources across the supply chain. End-to-end visibility.
Blockchain	Secure and transparent record-keeping of process parameters. Enhanced data integrity and immutability.	Tamper-proof records of safety checks and compliance. Transparent audit trails.	Decentralized, verifiable ledger for product journey. Improved recall efficiency and consumer trust.

Retort Process Optimisation

Adopted in the food preservation business, retort processing is an essential aspect in the commercial sterilisation of food items to attain food commercial sterility using heat processing. The process plays an important role in food safety practice as it will kill pathogenic and spoilage microorganisms, especially the Clostridium botulinum spore, which may lead to devastating food poisoning (Subhashis Chakraborty & Dharmendra Mishra, n.d). The technology entails warming up food to specific high temperatures under pressure for a fixed period that prolongs shelf-life and allows storing the food in ambient conditions (Jimenez et al. 2024).

Optimisation of retort processes is an ongoing process towards fulfilling the twofold goals of microbiological safety and optimum product quality. Parameters to be accurately regulated and measured during retorting include time and temperature, pressure, and other parameters. The efficiency of the thermal process is usually measured by the F0 value, expressing an equivalent time at a reference temperature (Fellows, 2022), needed to attain a given microbial reduction. Heat penetration data is also essential in accurate F0-calculation and defines how heat moves into the coldest part of the product in its package (Chen & Ramaswamy, 2002).

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The historical foundations in retort process optimisation include heat penetration experiments, mathematical modelling, etc. Heat penetration studies have been used to experimentally determine the temperature profile at the slowest heating point of a product during retorting. This information is further applied in the determination of the F0 value and setting of safe processing times. Heat transfer-based mathematical models are constructed to predict temperature distributions in products and optimise processing conditions without any time-consuming physical experimentation (Simpson et al., 2007). These models may be used to simulate different retort conditions and product formulations to determine the most effective and efficient sterilising cycles.

Despite these established methods, some challenges still exist in achieving optimal retort processing. Among these significant challenges is the intensity of energy that comes with upregulation of temperatures and pressure over longer durations. Not only does it add to operational costs, but it also affects the environment (Peesel et al., 2016). The other is the risk of over-processing, as food is exposed to excess heat, the point at which it becomes sterile. On the one hand, over-processing in terms of food safety can cause unwanted variations in the appearance of food and food's sensory characteristics like texture, flavour, colour, and nutritional content, which decreases product quality (Yu et al., 2023). On the other hand, under-processing also poses significant risks to food safety. This is also compounded by the natural inconsistency of raw materials, packaging materials, and retort equipment performance in the ability to record optimal processing results (Zhu et al. 2022).

To deal with these challenges, modern retort optimisation is increasingly using advanced technologies in solving problems. The real-time data of key process parameters can be obtained using sensors, e.g. thermocouples and pressure transducers, which allow more precise control achievement and monitoring of deviations in real time. Automation systems can dynamically adjust retort conditions based on feedback provided by a sensor, helping to reduce human error and provide better control over consistency. In addition, computational fluid dynamics (CFD) and advanced control algorithms are capable of both more complex modelling and real-time optimisation of heat flow in the retort, which results in more uniform heating and shorter processing times (Simpson et al., 2020). These technological innovations pave the way to amalgamating Smart Information Systems to optimise the retort processes further.

Food Safety in Retort Processed Products

Food safety means that food will not cause harm to the person who consumes or eats it in a way that does not represent an abuse of the intended use of the food (World Health Organisation, 2023). Food safety is of utmost importance in retort-processed products because they are intended to be shelf-stable, and they are not cooked after they are placed there. The thermal sterilisation process is therefore the most important control of the microbiological risk. The destruction of spores of the neurotoxin-producing anaerobic Clostridium botulinum is the most important issue in the retort processing, as spores of this bacterium produce one of the most potent neurotoxins even in minimal amounts, which is lethal (Solomon & Timothy, 2023).

To ensure the safety of retort-processed foods, stringent regulatory frameworks and standards have been established globally and nationally. In Malaysia, food safety is governed by the Food Act 1983 and Food Regulations 1985, which mandate compliance with various food safety requirements. Internationally, standards such as Hazard Analysis and Critical Control Points (HACCP) and ISO 22000 (Food Safety Management Systems) are widely adopted. HACCP is a preventive system that identifies, evaluates, and controls hazards significant to food safety, focusing on Critical Control Points (CCPs) where hazards can be prevented, eliminated, or reduced to acceptable levels (FAO & WHO, 2023). In the case of the retort processing, the thermal processing step itself is a critical control point, where such parameters as temperature, time, and pressure require little control and monitoring.

Typical food safety hazards in retort processing typically fall into three broad groups, which include microbiological, chemical and physical food safety hazards. Microbiological risks are considered most important, since the lack of adequate thermal processing may lead to survival and even growth of pathogenic microorganisms, such as spore-forming bacteria, for example, Clostridium botulinum and Bacillus cereus. Moreover, the integrity of the packages might also be problematic, as leaks or compromised seals may result in contamination of posts during the processes, compromising the safety of the product (Panghal et al., 2018). The

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chemical hazards can arise in many ways, including the inclusion of contaminants in raw materials like pesticides or heavy metals, the migration of harmful chemicals in packaging materials, and the production of unwanted chemicals throughout the processing stage, such as acrylamide. Although the retort processing mainly focuses on microbiological safety, it will be crucial to source raw materials extremely carefully and select proper packaging materials to decrease the risks presented by the chemicals (Onyeaka et al., 2023). In the meantime, physical hazard entails the accidental introduction of hazardous materials, usually glass, metal, plastic or wood, into the product during production or packaging. Even though these are slightly less directly related to the thermal process itself, they are also a gravely dangerous factor, as they have the potential to interfere with package integrity, potentially opening the door to microbiological recontamination (Onyeaka et al., 2023).

Food safety in retort-processed goods is multifaceted and encompasses various synergistic aspects. Among the most important is the monitoring of Critical Control Point (CCP), which necessitates constant monitoring of temperature, pressure, and time in the retort to ensure that the F 0 attained is adequate to ensure commercial sterility. Automated data logging systems, as well as alarms, can usually be used in this process to provide awareness of any deviations (Simpson et al., 2007). Process validation is another significant technique based on scientific and technical tests that ensure the thermal process is consistent in delivering an essential degree of lethality to destroy targeted microorganisms. Heat penetration tests and microbial challenge tests are some of the techniques that are at the epicentre of this validation process (Singh & Cadwallader, 2004).

To complement all these efforts, verification operations are conducted by conducting periodic audits and checks on the HACCP plan alongside other food safety management systems to ensure effective implementation of the various plans, coupled with the expected outputs. This involves calibration of instruments, scrutiny of records and Microbiological and Mach-B testing (Mortimore & Wallace, 2013). Furthermore, there is an emphasis on preventive controls, which include such practices as good sanitation, hygiene of personnel, following specifications of raw materials, and regular checking of equipment. These are preventive measures that are meant to minimise possible risks before they can jeopardise the safety of the product(FDA, 2004).

Although these comprehensive food safety management systems have robust frameworks, Small and Medium-sized Enterprises (SMEs) can find it very difficult to come up and sustain complete food safety management systems. Such needs are usually associated with insufficient financial capabilities to invest in new equipment and staff training, the absence of any technical skills related to food microbiology and process verification, the inability to receive current information concerning changes in regulations, and the high costs of maintaining numerous records (Talib et al. 2014). Such restrictions point toward a necessity of an innovative solution, i.e., a Smart Information System that can ease the process of compliance, ease the burden on operations, and improve the efficiency of food safety management overall in SMEs.

Traceability in the Food Supply Chain

Traceability in the food supply chain definition: Food supply chain traceability denotes the capacity to trace or trace the commodity over all manufacturing, processing, distribution steps, and farm to fork (Prajapati, 2016). It entails the recording of the history, place and use of a product or a component in one. Significance The role of traceability has become much more significant over the past decades due to rising consumer demands, regulatory requirements, and the necessity to efficiently prevent a crisis by managing a food safety incident or recall (Qian et al. 2022).

The supply chain traceability can be broken down into three general categories of traceability systems. The one-step forward system entails the location at the next step in the supply chain where the product has been shipped. On the other hand, a one-step back system is concerned with the origin of the product in the last immediate stage. Internal or full chain traceability is shown to be the most extensive and allows for tracing a product in detail within a single company or a whole chain. Such a system offers comprehensive details on the origins of the product, its processing history and distribution channel, thus giving more transparency and accountability (Smith & Furness, 2006).

Regular frameworks concerning traceability vary globally and have a trend that leans towards more wide-reaching and obligatory techniques. In Malaysia, the Food Act 1983 and its regulations, as well as the guidelines developed by the Ministry of Health and the Department of Veterinary Services, also highlight the importance of food businesses ensuring that traceability records exist. International customers tend to have more significant expectations, and so advanced traceability mechanisms are critical to export-leading food SMEs (International Trade Centre, 2015).

Different technologies are now applied to increase food chain traceability. Conventional methods involving paper-based documentation are being viewed as inefficient because they are error-prone, difficult to manage, and slow to access information. In contrast, modern systems make use of digital technologies that enhance accuracy, speed and increase transparency. Two of them, namely barcodes and QR codes, are most frequently used in identifying products and encoding data so that they can easily be scanned and data can be efficiently captured multiple times during the supply chain (Qian et al., 2022). Radio-Frequency Identification (RFID) yet enhances this further by providing the ability of automated data capture where there is no line-of-sight involved, thereby providing faster and more accurate tracking of products, especially at large-scale operations (Alfaro & Rxbade, 2009). Moreover, Enterprise Resource Planning (ERP) framework synchronises various business procedures, including production, inventory, and sales into one core, thus making the process of handling traceability data quite simple (Comba et al., 2013). Most recently, blockchain technology has become a potent method of traceability, and offers a distributed and tamper-proof record, where every transaction, like the flow of goods or processing operations, is stored as a blockchain. This will serve as an open and transparent history that can be accessed by all legitimate parties and will significantly increase trust, accountability, and deterrence of frauds all over the supply chain (Verna et al., 2025).

Small and Medium-sized Enterprises (SMEs) do not readily establish and sustain an effective traceability system despite the evident advantage. Such issues are high-upfront costs of technology and infrastructural installations, insufficiency of technocratic support to carry out and manage complex systems, incompatibility of disparate data sources throughout the supply chain, and lack of uniformity of data exchange protocols (Curto & Gaspar, 2021). Moreover, suspicion that traceability should continue being seen as a regulatory burden but not a strategic instrument may impair traceability adoption. In the case of Malaysian SMEs, these barriers present not only a commercial compliance challenge, but also a key to competitive advantage and the all-important development of consumer trust and access to hard-to-reach premium markets with high standards of required transparency.

Malaysian SMEs in the Food Processing Sector

Small and Medium-sized Enterprises (SMEs) form the core portion of the Malaysian economy, accounting for a significant portion of its Gross Domestic Product (GDP), employment and manufacturing. In the food processing industry, SMEs form most of the businesses, which are essential in the provision of both local and global markets, especially in the Halal food sector (Nor et al. 2016). These facilities are varied, and they comprise the traditional food processing businesses as well as the modern, technologically superior businesses.

Although the Malaysian SMEs operating within the sector of food processing contribute much to the economy, they are characterised by some peculiar features and issues which restrict their development, competitiveness, and eagerness to implement reliable technologies. Resource scarcity is one such major challenge whereby most SMEs run out of finances that they can utilise in expensive machines, new technologies, or exhaustive training programs. This usually limits their capabilities to renovate their facilities or have advanced management mechanisms (Talib & Ali, 2014). Moreover, the second problem is the lack of technical expertise, so that the high turnover of knowledgeable personnel in fields related to the latest technologies in processing, food safety management, and information systems is a barrier to the successful implementation and use of innovations (Manikas & Sundarakani, 2017).

Also, SMEs often face difficulties accessing finance. Despite the governmental programs, people often have challenges when trying to get enough money to develop the business, conduct research and development, or acquire a technology because of the harsh collateral criteria and the inability to plan the business properly (A. Rahman et al., 2023). The question of market access and market competitiveness is still of concern as SMEs struggle to comply with high-quality, safety, and traceability requirements of other countries, in addition to the stiff competition they receive both locally and internationally (Shamsudin et al., 2011). The burden of regulatory compliance can be increased as well because the demands of meeting the complex and changing requirements of food safety regulations, both internally and across borders, can be a strain on the SMEs with minimum compliance resources (Kettunen et al., 2017). Lastly, the barrier of innovation is a crucial challenge as most SMEs have low innovative potential because of deficient R&D, inadequate market intelligence, and inability to access technology transfer schemes, all of which lower their innovative capacity and possibility to remain competitive (Alam et al., 2016).

To appreciate the significance of SMEs, the government of Malaysia has started numerous programs and support policies to help in the growth of SMEs and embrace the use of technology. They include financial support packages, capacity building grants, technology modernisation grants, digitalisation, and Industry 4.0 enabling initiatives. Support and guidance are provided by the efforts of the agencies such as SME Corp. Malaysia, MARDI (Malaysian Agricultural Research and Development Institute), and FAMA (Federal Agricultural Marketing Authority) (SME Corp. Malaysia, n.d).

Malaysian SMEs' technology readiness and digitisation are one of the fundamental determinants of their potential to exploit Smart Information Systems. There is a general increase in the understanding of the advantages of digitalisation. At the same time, the uptake in practice is very different between various sub-sectors and enterprise size. It depends on such factors as management's perception of technology, employee readiness, and the availability of affordable and scalable solutions. A significant part of the SMEs remains at the initial stages of the digital transformation process and is likely to utilise primitive automation instead of comprehensive innovative solutions (Mohd Noor & Abdullah, 2019). This background illustrates the importance of bespoke practices and supportive ecosystems to enable effective SIS deployment in Malaysian food processing SMEs, particularly in processes such as retort sterilisation that are crucial for determining food safety and product quality.

FINDINGS AND DISCUSSION

The above literature review has provided the knowledge baseline about Smart Information Systems (SIS), the technicalities of retort process optimisation, the significance of food safety, the changing world of traceability and the peculiarities of the Malaysian SMEs working in the food processing industry. This section integrates all these factors to argue how SIS can be strategically used to improve retort functions, food safety, and enhance traceability among the Malaysian SMEs.

SIS for Retort Process Optimisation

Smart Information Systems (SIS) application is a revolutionary way of optimising retort operations, surpassing conventional manual controls and countermeasures. Use of IoT, Artificial Intelligence (AI), and Big Data Analytics to power SIS will create an entirely different standard of supply precision and predictive power that many SMEs could never access. Since devices are monitored and controlled in real-time, IoT sensors installed in retort chambers and other equipment systems constantly collect data on essential process parameters like temperature, pressure, F 0 value and more. This information is immediately updated within the SIS, providing the operators with a good understanding of the process and laying the groundwork to perform an operation that was previously checked manually, during periodic automated epochs. In the case of Malaysian SMEs, this will markedly decrease the risks of deviations and maintain consistency of the thermal treatment (Khamaludin, 2023).

Moreover, SIS allows predictive analytics to be employed to optimise processes: both AI and machine learning algorithms combine historical and real-time data and identify trends to predict problems in advance. Take the case of an SIS predicting that a retort may be at a sub-optimal temperature regime because of wear on equipment or changes in steam energy, and such concerns can be addressed in time, as the prediction was done in advance (Dhal & Kar, 2025). These predictive capabilities, in addition to providing optimal efficiency, also optimise the number of heating and cooling cycles of the products, limit over-processing of products to maintain optimal quality and nutritional levels, and save on energy expenditure (Simpson et al., 2023). Automated decision support in SIS is another valuable performance as the system guides the loading patterns, product-specific processing time and maintenance schedules based on past performance data. This lowers the use of human judgment and enhances consistency in operations, which is lucrative to SMEs that may lack dedicated engineers in processes (Simpson et al., 2007).

Last but not least, SIS leads to less waste and cost reduction in terms of reduced processing deviation and more efficient utilisation of resources. This covers deterring rejections of batches because of under- or over-processing, and limiting the unwarranted outlay of energy. In the case of the SMEs in Malaysia, such gains can be converted into increased yields and reduced operational expenditures with incremental profitability, which can lead to the manifestation of long-term sustainability (Ihueze, 2018).

SIS for Enhancing Food Safety

Food safety is not a bargaining point in the food sector, and Smart Information Systems (SIS) has a key role to play in the empowerment of the food safety management system, especially among smaller companies that strive to meet the toughest home and international regulations. An important SIS contribution capability is the automated monitoring of Critical Control Point (CCP), whereby sensors continuously monitor parameters like the F0 value and retort temperature. Not only does the system store the data, but it also can give an instant alarm to operators or automatically put the processes on hold in case the parameters go out of critical levels, minimising the possibility of human error and providing constant compliance with the most important safety procedures (Panghal et al., 2018). Moreover, the SIS supports early warning systems and predictive risk assessment by analysing data from various sources, such as results of processing raw materials, the quality of processing conditions, and environmental conditions. This enables the system to predict risks before they take place, like indicating when there is a recurring change in the temperature to notify the system about a forthcoming malfunction in the equipment assets, to both preempt the equipment malfunction and reduce safety risks (Qian et al., 2022).

The other important benefit is how SIS enables compliance with regulations and audits. Automated record-keeping of CCP monitoring, calibration cylinder, and sanitation schedules generated by SIS provides a complete, traceable digital record that is easy to comply with concepts like HACCP and ISO 22000 (Mortimore & Wallace, 2013). To the Malaysian SMEs, this helps cut down administrative tasks and make them much more prepared to get inspected as well as certified in order to expand access to the international markets further. In addition to process monitoring capabilities, SIS can do more in the way of improved hygiene and sanitation management, including, not exclusively, integrating environmental sensor data to monitor hygiene status conditions, acceptable cleaning schedules, and even staff movement in order to make sure that proper sanitation standards are being followed. Such a comprehensive observation system enhances the general reassurance of food safety and aids in the establishment of healthier production conditions (FDA, 2004).

SIS for Improving Traceability

Traceability is now an important part of the modern food industry, and it can be the basis of consumer confidence, brand name, and recall program functioning. The technological foundation to implement technically solid and transparent traceability systems is Smart Information Systems (SIS), which are especially beneficial to SMEs working in the ever-more complex supply chain. Integrated data management across the products enables SIS to collect information at each level of the supply chain, from raw materials to distribution and retail. This covers important information like source of raw materials, retort batch numbers, F0 values, packaging details, and distribution channels, thus eliminating piecemeal manual records in favour of a single data system (Smith & Furness, 2006).

By using blockchain technology that creates timeless, non-editable, and transparent records, traceability is also improved. Individual stages in the retort process, loading, and cooling, among others, may be recorded on the blockchain, resulting in a verifiable history of the product. The given feature not only creates trust between supply chain partners and consumers but also increases brand credibility and demonstrates compliance with regulations and market demands (Verna et al., 2025). Moreover, SIS will facilitate more efficient and precise reactions to recall, so impacted products can be recalled in time and traced in case of a food safety incident.

This aspect drastically decreases the extent of recalls, limits economic losses, and protects the brand reputation, all of which are of utmost importance to SMEs with limited resources (Qian et al., 2022).

Lastly, there is increased traceability that helps lead to consumer trust and increased access to the market. Regulation of transparency and verifiability of the data related to the products will help SMEs develop a better relationship with consumers, as well as enable them to exceed the stringent standards of traceability of the international market. This, by extension, not only raises the confidence of the consumers but also enables Malaysian food SMEs to compete better internationally (Shamsudin et al., 2011).

Illustrative Mini-Case Study: A Malaysian Rendang SME

The proposed Smart Integrated System (SIS) demonstrates the real-world usage example; assume a hypothetical SME in Malaysia called Rendang Bestari that is located in the state of Johor and manufactures and packages ready-to-eat beef rendang through retort technology. Some of the typical problems that the company experiences like many SMEs include inconsistent quality of products due to the variation of manual retorting, high electricity bills, and inability to comply with detailed traceability expectations of international customers that export the products. On a default setting, retort temperature and processing time in Rendang Bestari are set manually and checked by operators which may lead to an over-cooked batch which may affect the texture or product which is not processed completely thus leading to issues with food safety. The paper-based logs used to monitor critical control points (CCPs) every 30 minutes implies that the disposal of a whole batch may be necessary in case of any identified deviation. Likewise, production dates and batch numbers are tracked manually, and so it is exceedingly time consuming to track down a certain pouch of rendang to a particular batch of raw material.

The company uses a stage-by-stage approach to deal with these problems by adopting SIS. Phase 1 designed to equip its retorts with IoT sensors that will detect real-time temperature, pressure, and processing time data and feed the information to a cloud-based dashboard, eliminating manual errors and enhancing consistency of batches. Phase 2 consists of introducing machine learning algorithms to detect the most appropriate processing times during the collection of several months of data, depending on the weight and composition of the rendang, reducing energy consumption by 15 percent without changes in F0 values to ensure microbiological safety. Phase 3, which involves combining the SIS with the inventory system, includes QR codes on the product packaging. With a mere scan, the end-to-end history of the product can now be known, including retort batch, IoT sensor reads, supplier, and packaging date, bringing a mock recall exercise to a one day timeframe down to under five minutes.

Due to this digital change, Rendang Bestari is able to decrease product rejections by 20 per cent, satisfy high international standards in traceability and enhance the brand image of safety and quality. This is a synthesized example of the industry challenges and solutions presented in the literature that show how the Malaysian SMEs can strategically use Industry 4.0 technologies to receive a competitive advantage (Jagtap, 2021; Khamaludin, 2023).

Challenges and Enablers for SIS Adoption by Malaysian SMEs

Though the advantages of Smart Information Systems (SIS) are enticing, the implementation and adoption of the same in the case of Malaysian SMEs have various obstacles. The high cost of initial investment is one of the most urgent obstacles where the cost of purchasing SIS hardware components, including sensors and internet of things devices, as well as software platforms and analytics tools, might necessitate a significant amount of capital that most SMEs with limited resources may not because of the limited resources (Abdul Talib & Mohd Ali, 2014). The absence of technical expertise is equally problematic as most SMEs lack professionals trained in data science, AI, IoT, or system integration as they are required to manage and optimise SIS at least to some extent (Manikas & Sundarakani, 2017). In addition to technical deficiencies, the level of awareness about the benefits of SIS remains insufficient, and some SMEs consider such technologies as unwarranted costs instead of medium- and long-term strategic investments that are likely to increase competitiveness (Mohd Noor & Abdullah, 2019).

The issue of data security and privacy is another barrier, given that SIS have to use sensitive operational and

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product data. In the case of smaller businesses, adoption may be discouraged by the fear of a cybersecurity breach or information leak (Alam et al., 2016). Moreover, the unwillingness of employees accustomed to traditional practices to change can be another impediment to seamless changes to the digital system. Therefore, change management activities and training of the workforce are required (Alam et al., 2016). Last but not least, the issue of poor digital infrastructure persists, especially among the SMEs located in rural settings, where internet connection and other digital support structures are poor. This has restricted the possibility of sustaining advanced SIS solutions due to the poor underpinning infrastructure (Mohd Noor & Abdullah, 2019).

Nevertheless, several factors can facilitate the successful implementation of Smart Information Systems (SIS) in the Malaysian SMEs. The most important is whether the government grants and benefits, i.e., targeted financial support, subsidy, and tax waiver, exist to facilitate the overall cost of adoption and make SIS more affordable to smaller companies (SME Corp. Malaysia, n.d). Moreover, technology providers and industry associations contribute to the whole situation by proposing low-cost, expandable, and adaptable SIS solutions. Such partnerships not only equip SMEs with technologies that are customisable but also give them training and a technical understanding that serve to overcome the knowledge gap (Talib et al., 2014).

Training and capacity-building programs as an enabler are another solution, as this allows employees of SMEs to acquire the necessary digital literacy skills as well as a skillset to understand data analytics and SIS management better, thus enabling SMEs to operate and reap the rewards of such systems (Manikas & Sundarakani, 2017). Besides, it can give examples of success stories among the early adopters as one of the most effective motivators can provide confidence among the rest of SMEs through vivid examples of efficiency gains, cost savings, and increased competitiveness (Mohd Noor & Abdullah, 2019). Lastly, the creation of harmonised systems, specifically in data exchange mechanisms and interoperable systems, may help streamline integrations between different SIS components and facilitate the ease of data flow up and down the supply chain to enhance reliability and efficiency of the system (Curto & Gaspar, 2021).

It is estimated that Malaysian SMEs can take strategic steps in transforming their retort process by proactively tackling such issues and using SIS enablers readily available to them to reap the benefits of an even greater degree of food safety, achieve complete traceability, and ultimately be more competitive in the ever-changing food industry.

Cost-Benefit Analysis and Scalability for SMEs

Although the advantages of Smart Integrated Systems (SIS) are clear, its implementation in SMEs would depend on positive cost-benefit analysis and scaling technology to the relevant context of the SME needs. An examination of literature on the adoption of technology in manufacturing reflects a general model of assessment of technology adoption. In terms of the cost factor, the biggest impediment is the capital investment (CAPEX) that consists of sensors, data acquisition hardware and software license and cloud subscription fees that may be needed. In the case of a small retort operation, this may be as little as a few thousand dollars to install a basic sensor setup or even tens of thousands to install an all-encompassing system powered by AI. There is also the cost of implementation and integration, which includes the installation of hardware and the integration of SIS with already existing machinery and software including inventory management systems. Besides this, SMEs need to consider the cost of training and development of skills to enable employees to be competent in operating and maintaining the new system. Finally, operational expenditures (OPEX) persist in the form of software subscriptions, cloud storage, system maintenance, and data security.

The economic benefits that SIS offers SMEs are concrete, and they offset these costs. Automation helps improve operational efficiency through decreasing energy usage per retort cycle, decreasing processing time, and decreasing labour costs. Another benefit is waste reduction since not as many batches are discarded due to over or under-processing, and predictive alerts are used to avoid spoilage. There is also enhanced compliance and market access, reduced costs in the areas of audits and compliance reporting, and access to profitable export markets, which require very high standards of traceability. In addition, the implementation of SIS enhances brand image by elevating consumer confidence in the brand and brand reputation value by making demonstrable promises to food safety and quality.

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Scalability is central to SIS adoption by SMEs, which is why SIS adoption is possible in SMEs. Instead of a high-cost big bang adoption, it is better to adopt the method of a slow and scalable adoption. Companies may begin small, by digitalizing just one production line or even one retort, with initially simple in-time monitoring of temperature and pressure as the initial target, and will allow a rapid payback period and a confidence in the system internally. The utilization of cloud-based Software-as-a-Service (SaaS) solutions will also allow cutting down the initial spending by transforming the massive capital investments into smaller, more manageable, monthly operations costs and removing the necessity of having to maintain in-house servers. Moreover, SMEs are advised to concentrate on areas of high impact which would solve their most urgent problems, be it energy efficiency, batch consistency, or fulfil the traceability needs of the important clients. When presented with the concept of SIS adoption as a stepping stone process to be undertaken in a scalable manner as opposed to a one-time big-scale project, the Malaysian SMEs will be able to build a powerful business case, realize a slow but steady benefit as their resources and expertise build up.

Measurable KPIs for SIS Success

In order to convert theoretical advantages of Smart Integrated Systems (SIS) into working business ratios, Malaysian SMEs ought to define and track certain, quantifiable Key Performance Indicators (KPIs). As per the current reports released by industry leaders in digital transformation in manufacturing, the achievements of the implementation of SIS can be measured in three primary areas using reports released by Malaysian Investment Development Authority (MIDA) and SME Corp. As part of process optimisation, KPIs are: Overall Equipment Effectiveness (OEE), a metric of the availability, performance, and quality of retort machines; energy consumption per batch, a metric of the kilowatt hours each retort cycle uses, in order to demonstrate energy savings; and cycle time, which is an indicator of the average time per retort process. As an indicator of food safety and quality, it would be important to monitor Critical Control Point (CCP) variances to guarantee that food temperatures do not exceed safe levels, decreasing the rate of product rejections by decreasing the percentage of defective or unsafe food batches and keep track of customer complaints in order to determine product uniformity and customer satisfaction. KPIs like mock recall time, a measure of how fast a product can be traced back to the consumer and raw material source (best-in-class performance is less than five minutes) and traceability data accuracy, a measure of the percentage of products with complete and correct historical data, are important benchmarks in terms of traceability. By paying particular attention to these KPIs systematically, SMEs can not only improve their business case to implement the SIS but also be able to track the payback of the investments made and foster an ongoing increase in operational performance, safety, and competitiveness.

CONCLUSION

The literature-based review conducted in this paper has shed ample light on the transformational prospects of Smart Information Systems (SIS) in terms of optimisation of the retort process, improvement of food safety and traceability of Malaysian Small and Medium-sized Enterprises (SMEs). The research has integrated analysis based on various industry and academic sources, and with the synthesis of the conceptual framework has achieved clarity over how SIS with the use of technologies like IoT, AI and Big Data Analytics, can help resolve the urgent concerns around operational and regulatory challenges being faced by these key drivers of the economy.

This paper has shown that SIS may play a significant role in optimising the retort process in terms of real-time monitoring, predictive analytics, and automated decision support, resulting in more efficient operations, minimising waste and improving the quality of the products. Moreover, SIS are also beneficial in enhancing food safety through the automation of monitoring Critical Control Point (CCP) to perform predictive risk and facilitating regulatory compliance. More importantly, the newly established traceability built with the help of these systems, data integration throughout the supply chain, and efficient and fast recall management ensure the development of consumer trust, potentially expanding to new market possibilities. Although there are some obstacles, such as high start-up costs, a lack of technical knowledge in the industry, and the reluctance to change, the strategic imperative for SIS adoption by SMEs in Malaysia is evident. It could lead to improved competitiveness and sustainability for SMEs.

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