International Journal of Basic and Applied Sciences, 14 (6) (2025) 128-138

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS
https://doi.org/10.14419/pg8mnw78
Research paper

Smart Monitoring of School Nutrition: An IoT Enabled Approach to Evaluating The Free Nutritious Meal Program

Dedi [1], Muchamad Iqbal [2], Jarudin [2] *, Nova Teguh Sunggono [2]

[1] *Dept. of Business and Management, Institut Teknologi dan Bisnis Bina Sarana Global, Tangerang, Indonesia*
[2] *Dept. of Information Engineering, Teknologi dan Bisnis Bina Sarana Global, Tangerang, Indonesia*
**Corresponding author E-mail: dedi@global.ac.id*

Received: September 16, 2025, Accepted: September 23, 2025, Published: October 8, 2025

Abstract

This study designed and piloted an IoT-enabled monitoring framework for school nutrition programs. The system incorporated temperature, humidity, and food weight sensors, with RFID tracking for logistics and cloud-based dashboards for analysis. Evaluation indicators included compliance with national nutrition guidelines, distribution timeliness, food safety parameters, and stakeholder feedback. Pilot deployment demonstrated that the IoT framework enhanced monitoring accuracy, reduced food wastage, and ensured greater adherence to nutritional standards. Data from sensors enabled early detection of temperature deviations and logistic delays, while dashboards facilitated evidence-based decisions by administrators. Preliminary outcomes also suggested improved student attendance and satisfaction due to more reliable meal provision. IoT-enabled intelligent monitoring provides a scalable and transparent solution for evaluating a free nutritious meal program. This approach supports national policy objectives by strengthening accountability, improving service delivery, and generating actionable insights, and contributes to better child health and education outcomes. Future research should expand deployment at scale and integrate predictive analytics to optimize program management further.

Keywords: *IoT; School Nutrition; Free Meal Scheme; Intelligent Monitoring; Makan Bergizi Gratis (MBG).*

1. Introduction

School-based nutrition programs have increasingly been recognized for their vital role in improving child health outcomes, educational achievement, and overall well-being. The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) emphasize that adequate nutrition during childhood is essential for proper growth and cognitive development [1]. Free meal schemes have successfully addressed child malnutrition in several countries, including India, Brazil, and Indonesia, particularly among socio-economically disadvantaged populations [2], [3]. These programs have been linked to enhanced dietary diversity and improved school attendance rates, illustrating the multifaceted impact of nutrition on education and health [4]. However, the implementation of large-scale school meal programs faces numerous challenges. Issues such as inconsistent food quality, insufficient alignment with nutritional guidelines, food safety concerns, and logistical inefficiencies can hinder the effectiveness and sustainability of these initiatives [5]. Traditional monitoring approaches often lack the necessary rigor, relying heavily on infrequent inspections and manual reporting protocols. This can lead to a significant disconnect between policy intentions and tangible outcomes in schools [6]. The literature indicates that many of these issues could be mitigated with more robust monitoring and evaluation strategies that employ innovative technological solutions [7].

The advent of digital technologies, particularly the Internet of Things (IoT), presents unprecedented opportunities for enhancing the effectiveness of school nutrition programs. IoT applications in various sectors have demonstrated real-time monitoring and data analytics potential, facilitating improved decision-making processes [8]. In school meal schemes, IoT systems can continuously monitor critical parameters like food temperature, storage conditions, and nutritional content, while integrating data on student health and attendance [9]. By employing these technologies, stakeholders can create a transparent evaluation framework that ensures compliance with nutritional standards and connects program outcomes to broader health and educational indicators [10].

The intersection between IoT technology and school nutrition programs is still relatively unexplored, especially regarding large-scale governmental initiatives. While existing studies have focused on the benefits of nutrition programs and the efficacy of IoT in related fields, comprehensive research synthesizing both domains is lacking [11]. Thus, this research endeavors to develop and pilot an IoT-enabled monitoring framework explicitly tailored for free nutritious meal schemes. By evaluating the impact of IoT technologies on food safety, nutritional compliance, and logistical efficiency, this study aims to provide actionable insights for policymakers and practitioners to enhance both the delivery and quality of nutrition programs for children [12]. The systematic integration of IoT into school nutrition programs could revolutionize monitoring and evaluation processes, addressing enduring challenges while better aligning program implementation with intended health outcomes. This research will contribute significantly to the existing discourse on digital transformation in public health, advocating for evidence-based approaches that enhance educational experiences and ensure healthier futures for vulnerable populations.

Free nutritious meal programs are critical for addressing malnutrition and improving learning outcomes, yet challenges in monitoring often undermine their implementation. Manual reporting and periodic inspections provide limited visibility into food safety, nutritional adequacy, and logistic efficiency, creating contamination risks, waste, and inequitable distribution. Although digital technologies and IoT applications have advanced rapidly in agriculture, food safety, and health care, their integration into school nutrition monitoring remains limited. Existing studies focus on nutrition program evaluation or IoT applications in supply chain management, without bridging the two in a comprehensive framework. Consequently, there is insufficient evidence on how IoT can enhance accountability and outcomes in large-scale, government-led school meal programs.

Research objectives:

1) To design and implement an IoT-enabled monitoring framework tailored to the free nutritious meal programs.
2) To evaluate the framework's capacity to ensure food safety, verify nutritional compliance, and improve logistic efficiency.
3) To link monitoring data with student-level outcomes, such as attendance and fundamental health indicators, thereby generating evidence for policy and program improvements.

This study offers theoretical and practical contributions to public health, education, and digital innovation. From a practical perspective, the study provides policymakers and program implementers with a scalable framework to improve accountability, transparency, and efficiency in free nutritious meal schemes. The IoT-based system allows real-time tracking of food safety, nutritional compliance, and logistic performance, thereby reducing wastage and minimizing contamination risks. By linking program monitoring with student attendance and health outcomes, the framework generates actionable insights for education and health ministries, enabling evidence-based decision-making. Furthermore, the findings highlight opportunities and barriers for adopting digital innovations in resource-constrained school environments, offering guidance for future large-scale implementation.

2. Literature Review

2.1. Global experiences in school meal programs

School feeding programs (SFPs) are critical in improving nutritional outcomes for children, particularly in developing contexts. However, monitoring systems across different countries exhibit significant variability in scope, technology use, and data accuracy. The Mid-Day Meal Scheme (MDMS) in India exemplifies a traditional approach that relies on manual inspections and paper-based reporting to ensure compliance with nutritional standards. While local inspections can provide accountability, they are often hindered by reporting delays, inaccuracies, and a lack of real-time decision-making capabilities, as indicated by analyses of traditional monitoring methods [13]. These obstacles can delay responses to critical issues affecting child nutrition and food quality. Conversely, the Portuguese National School Food Program (PNAE) employs a centralized approach that implements structured guidelines and periodic audits to align its practices with nutritional benchmarks. However, this method has similar limitations, such as dependency on scheduled visits that fail to capture daily variations in food quality and children's consumption patterns [14]. The reliance on retrospective data collection inhibits timely interventions and adjustments needed to enhance program effectiveness. Indonesia's Program Makan Bergizi (PMB) represents a recent commitment to institutionalizing nutrition within schools. Launched to improve children's dietary habits, the program faces challenges from varied geographic and socio-economic conditions that hinder consistent implementation. As noted in a review by Karmini et al. [15], while PMB has established monitoring and quality assurance frameworks, it still grapples with geographical disparities and resource limitations. These ongoing challenges highlight the necessity for enhanced monitoring mechanisms to ensure the program's effectiveness across different contexts.

The experiences of these three countries underscore the global importance of school meal programs while highlighting common issues related to monitoring and Evaluation. Recent studies emphasize the need for stronger frameworks to assess the impacts and effectiveness of school feeding programs comprehensively [16], [17]. Integrating modern technologies, such as digital monitoring tools and IoT solutions, could address some of these gaps by improving the transparency and accountability of school meal initiatives, as pointed out by contemporary studies on public health interventions [18]. Existing school-feeding and nutrition monitoring systems vary considerably in scope and technological integration. For instance, India's Mid-Day Meal Scheme (MDMS) has primarily relied on manual inspections and paper-based reporting to track compliance with nutrition and hygiene standards. While such inspections provide accountability at local levels, studies highlight significant reporting delays, data accuracy inconsistencies, and limited real-time decision-making scalability [19].

In light of these challenges, IoT-based monitoring frameworks present a potential solution that addresses the shortcomings of existing systems. IoT technologies can significantly improve nutritional oversight by utilizing interconnected sensors and real-time data dashboards. Unlike MDMS's traditional inspections, IoT systems can automatically log vital parameters such as food temperature, portion sizes, and delivery times [20]. This capability minimizes reporting lags and enhances the timeliness of data, enabling stakeholders to respond more swiftly to potential risks like food contamination or cold chain failures. Additionally, the predictive analytics enabled by IoT frameworks allow for the early detection of emerging issues, thereby preventing them from escalating into broader programmatic crises [21]. While traditional school feeding programs such as MDMS and PNAE provide valuable frameworks for improving child nutrition, they are constrained by significant operational deficiencies. The integration of IoT solutions offers a paradigm shift, enabling continuous monitoring and immediate response capabilities that could considerably enhance the nutritional outcomes of these initiatives.

This comparison suggests that IoT-based systems enhance accuracy and timeliness and expand the scope of monitoring from compliance-checking to proactive risk management. Nevertheless, challenges remain, particularly regarding the cost of infrastructure deployment in resource-limited contexts and the need for robust data governance to ensure privacy and reliability. Table 1. Style comparison (columns: MDMS, PNAE, IoT framework; rows: Monitoring Approach, Data Accuracy, Timeliness, Limitations.

Table 1: Comparative Analysis of Monitoring Approaches in School Feeding Programs

Aspect	MDMS (India)	PNAE (Portugal)	IoT-based Framework (Proposed)
Monitoring Approach	Manual inspections; paper-based reports	Centralized guidelines; periodic audits	Real-time monitoring via IoT sensors and digital dashboards
Data Accuracy	Variable; prone to reporting bias and omission	Relatively structured, but dependent on human audits	High; automated collection reduces human error

Timeliness	Delayed (reports submitted after inspections)	Moderate; audit cycles not real-time	Immediate, real-time data available for instant analysis
Scope of Monitoring	Focus on compliance and hygiene checks	Nutritional benchmarks and compliance verification	Multi-dimensional (food quality, temperature, logistics, consumption)
Advantages	Simple, low-cost, community-based oversight	Clear standards; government accountability	Continuous monitoring, predictive analytics, and proactive risk detection
Limitations	Time lag, inconsistency, and limited scalability	Lack of daily fluctuation capture, retrospective	Infrastructure cost, digital divide, and data governance needs

2.2. Challenges in monitoring and evaluation

Effective monitoring is essential for the success of large-scale nutrition programs. However, many of these initiatives still depend heavily on traditional methods such as manual reporting, administrative inspections, and paper-based audits. These methods often result in delayed, fragmented, and inaccurate reporting, which can lead to significant underreporting of critical data [22]. Key challenges faced in this context involve adhering to food safety standards, verifying nutritional adequacy, preventing logistical delays, and minimizing food wastage, all exacerbated by the lack of reliable real-time data.

The monitoring of food safety remains a critical area of concern. Without real-time data, it becomes increasingly complex for policymakers to swiftly identify issues such as food contamination or failures in adhering to nutritional standards. This issue is prevalent in large programs like India's Mid-Day Meal Scheme, where significant gaps exist between intended policy outcomes and actual health benefits experienced by schoolchildren [23]. The reliance on outdated reporting methods can lead to considerable delays in addressing these health and safety concerns, ultimately diminishing the effectiveness of nutrition interventions. The challenge of verifying nutritional adequacy is compounded by limitations in current evaluation frameworks. According to Trapp et al. [24], without systematic assessments incorporating rigorous nutritional monitoring, the actual impact of school feeding programs on children's health may remain obscured. Programs need to collect and analyze data effectively to establish clear links between food quality and health outcomes, which is currently hampered by inefficient monitoring practices.

Logistical efficiency is another area where traditional monitoring methods fall short. Efforts to streamline operations are often undercut by delays in food delivery, inconsistent meal preparation, and poor inventory management. These inefficiencies contribute to food wastage and hinder the timely service to students, especially in resource-constrained settings that are common in developing nations [25]. A cohesive and responsive logistical framework is essential in mitigating these risks; however, it often remains unattended due to inadequate supervision and capacity-building efforts. The challenges of monitoring and Evaluation in school meal programs can ultimately lead to a divide between policy objectives and the on-ground realities children face. To bridge this gap, incorporating innovative digital solutions for monitoring is crucial. For example, IoT-based monitoring tools could provide stakeholders with immediate access to data, enabling timely interventions and enhancing the overall efficacy of nutrition programs. Such advancements, if adopted, could significantly transform the landscape of nutrition monitoring in schools, leading to improved health and educational outcomes for children globally.

2.3. IoT applications in related domains

The Internet of Things (IoT) has demonstrated transformative potential in various sectors intersecting nutrition monitoring, enhancing efficiency, transparency, and decision-making. IoT sensors are critical in ensuring compliance with Hazard Analysis and Critical Control Points (HACCP) standards in food safety by continuously tracking parameters such as storage temperature, humidity, and microbial risks. This real-time monitoring reduces the likelihood of foodborne illnesses and ensures that food served in school meal programs is safe for consumption [20, [25]. The application of IoT in supply chain management through Radio-Frequency Identification (RFID) tags and GPS technologies enables end-to-end visibility, mitigating delays and improving accountability in food distribution. These tools facilitate better tracking of food items from farm to school, ensuring that children receive fresh and nutritious meals, which aligns with improving dietary quality in nutrition programs [26]. As noted by Junita & Yuniantol.[27] Integrating such technologies can help streamline logistics and consistently meet nutritional goals across diverse geographic regions.

In the healthcare sector, IoT has been leveraged for remote monitoring of patient health indicators, showcasing its ability to integrate environmental data with individual health information. This linkage is crucial for understanding the broader context affecting children's nutritional statuses. For instance, databases combining ecological and personal health data can inform targeted interventions for at-risk populations [24], [28]. The potential of IoT to enhance healthcare monitoring highlights its applicability in school nutrition initiatives, where maintaining optimal conditions and monitoring health outcomes are vital.

Despite these advances, the application of IoT within school nutrition programs remains limited. Current research predominantly emphasizes its efficacy in food safety, supply chain management, and health care, with a notable gap in empirical studies assessing its implementation in school-based nutrition systems [29]. This is particularly pertinent in contexts such as school feeding programs in developing nations, where implementing technology can face infrastructure, training, and funding hurdles. Significant improvements in program accountability, food safety, and nutritional compliance could be achieved by addressing these barriers and expanding IoT applications into school meal monitoring. While the IoT presents numerous opportunities for enhancing nutritional monitoring and Evaluation, its integration into school nutrition programs has not yet been fully realized. However, lessons from its successes in related domains provide a foundational understanding of navigating implementation challenges, identifying potential benefits, and improving children's health and education outcomes through better nutrition.

2.4. Identified research gap

Integrating the Internet of Things (IoT) into school meal monitoring frameworks has garnered attention due to its potential to enhance the effectiveness of nutrition programs, especially in ensuring food safety, efficiency, and accountability. However, as the literature currently stands, there is a notable gap in exploring interdisciplinary approaches combining IoT technology with nutrition interventions specifically designed for schools. Most studies thus far have examined nutrition program evaluations and IoT applications as separate entities rather than interconnected systems that could yield greater insights into student health and educational outcomes.

While existing research elucidates the significance of school feeding programs in improving children's nutrition and educational engagement, there remains limited empirical evidence linking operational metrics such as food temperature, delivery timeliness, and nutrient adequacy to direct student health outcomes. For example, Foeken & Mwangi [30] comprehensively review school feeding programs in developing countries, indicating positive impacts on energy intake and school attendance. Still, they do not specifically discuss the integration of IoT frameworks for monitoring purposes. Similarly, Sekiyama et al. discuss the implementation challenges and effectiveness of school feeding programs in Indonesia, yet their focus is not on IoT solutions for monitoring these programs [21]. Additionally, Lakshmi et al.[31] explore alternative models for school feeding in conflict-affected settings, suggesting that dietary diversity can be qualitatively assessed through methods like dietary diversity scores. However, they do not address IoT methodologies that could enhance real-time monitoring systems. Furthermore, while data-driven approaches utilizing IoT technology could strengthen the connections between nutritional adequacy and improvements in student outcomes, further exploration is necessary, as current literature does not directly link IoT applications with cognitive and physical development outcomes in students [32].

The proposal of an IoT-enabled monitoring framework represents an essential step toward rectifying these gaps. This framework could facilitate the real-time collection of operational metrics, allowing schools to enhance transparency and understand how these factors correlate with students' nutritional status and broader educational outcomes. The proposed system aims to evaluate free nutritious meal schemes more effectively, addressing existing research and practice inadequacies. Although the literature on nutrition and its implications for health and education is robust, a critical interdisciplinary gap exists regarding integrating IoT technologies into school meal monitoring frameworks. This unexplored terrain holds significant promise for advancing school nutrition programs and enhancing their effectiveness in improving student outcomes..

3. Materials and Methods

3.1. Study design

This study used a mixed-methods approach to develop and pilot an IoT-based framework for monitoring the free school nutrition meal (FFM) program in Tangerang City. This two-phase design facilitated the integration of technology with practical applications, improving data collection and program evaluation. The framework was designed to address the specific monitoring needs of the free school nutrition meal program, leveraging a sensor network to collect real-time data on food consumption and nutritional quality. Technologies such as smart home devices and natural language processing were integrated to improve the accuracy of dietary intake reporting, surpassing traditional self-reporting methods [17]. The pilot phase of the digital dashboard implementation involved five public elementary schools in Tangerang City and 150 sixth-grade students over five days. Workshops with child stakeholders were conducted to identify factors influencing food choices, which informed the design and implementation of the framework [33]. While the mixed-methods approach offers a robust framework for monitoring school nutrition programs, challenges remain in ensuring consistent implementation across different school settings, particularly in adapting to external factors such as socio-economic disparities and changing health policies [16].

3.2. IoT- enable monitoring framework

Integrating IoT and digital tools in monitoring systems across domains such as food safety, nutritional compliance, logistics, and student outcomes is a transformative approach that leverages real-time data for enhanced decision-making and operational efficiency. This system utilizes a combination of hardware, like sensors, RFID, and GPS devices, alongside software solutions such as cloud-based analytics, dashboards, and mobile applications, to ensure continuous monitoring and feedback. This integration improves the traceability and safety of food supply chains and enhances operations' nutritional compliance and logistical efficiency, ultimately impacting student outcomes positively. IoT and AI technologies are pivotal in enhancing food safety by improving traceability and reducing food waste through real-time monitoring and data analytics. These technologies help maintain food quality and safety from production to consumption [5]. Digital technologies in food supply chains can significantly reduce food loss and waste, a critical issue affecting economic growth and environmental sustainability [34], [35]. IoT solutions, such as real-time anomaly detection systems, are crucial in maintaining the integrity of cold chain logistics, thereby minimizing food spoilage during transportation. This is achieved by continuously monitoring temperature and other critical parameters, ensuring that perishable goods remain within safe limits.

Integrating blockchain with IoT in food supply chain management enhances transparency and traceability, providing stakeholders with reliable data on food conditions and logistics, which is essential for efficient distribution [36], [37]. Monitoring systems in educational settings can benefit from IoT architectures that facilitate efficient data collection and analysis, thereby improving the learning environment and student outcomes. The use of IoT in education is shown to enhance user convenience and operational efficiency [38]. In school health and nutrition programs, selecting appropriate monitoring indicators and using digital tools can provide critical insights into program effectiveness, helping to adapt strategies to improve student health outcomes [16]. While integrating IoT and digital tools offers numerous benefits, challenges such as data privacy, the complexity of implementation, and the need for robust infrastructure must be addressed. Additionally, the environmental impact of digital technologies, particularly in terms of energy consumption, is a concern that needs to be mitigated through sustainable practices and technologies, such as green blockchain solutions [37]. These considerations are crucial for successfully deploying and operating such monitoring systems across various domains.

A summary of the evaluation framework is presented in Table 1, outlining the domains, indicators, and monitoring tools.

Table 1: Evaluation Indicators for IoT-Enabled School Nutrition Monitoring

Domain	Indicators	Monitoring Tools
Food Safety	Temperature, humidity, microbial safety (HACCP parameters)	Temperature & humidity sensors, intelligent packaging alerts
Nutritional Compliance	Calorie adequacy, macronutrient balance, micronutrient sufficiency	Digital meal composition tracking, nutrition databases
Logistics & Distribution	Delivery timeliness, coverage rate, and food wastage	RFID tracking, weight sensors, and GPS-based route monitoring
Student Outcomes	Attendance, BMI, anemia screening, and satisfaction surveys	Integrated dashboards, survey apps, and health record linkage

3.3. Data collection

Data collection combined sensor-based monitoring with field-based observation and survey methods. Sensors recorded continuous data on food storage and delivery conditions, while RFID and GPS tracked distribution flows. Nutritional compliance was evaluated by recording meal composition and cross-referencing it with national dietary standards. Student outcomes were assessed through attendance logs, anthropometric measurements (BMI), anemia screening, and structured satisfaction surveys.

3.4. Data analysis

Integrating cloud-based data aggregation and analysis platforms in educational settings has shown significant potential in enhancing compliance with safety and nutritional standards, logistic efficiency, and student-level outcomes. These platforms utilize real-time dashboards to visualize trends and flag deviations, while qualitative feedback from stakeholders provides insights into the system's usability and acceptance. Various studies support this approach by highlighting the benefits and challenges of implementing such systems in educational environments.

The Open-source Smart Register Platform (OpenSRP) facilitates real-time data management in educational settings, allowing for timely data entry and access through secure dashboards. This system has demonstrated high timely data submission and quality rates, which are crucial for effective monitoring and decision-making in educational contexts [39]. IoT and cloud computing technologies are pivotal in Education 4.0, enabling real-time tracking and irregularity detection in academic institutions. These technologies support the visualization of data trends and the generation of alerts for deviations, thus enhancing the responsiveness of educational management systems [8].

The National School Lunch Program in the US has been analyzed for its alignment with the EAT-Lancet Commission's dietary standards. The study found that current school lunches often exceed recommended targets for specific food groups, suggesting a need for redesign to improve nutritional quality and environmental sustainability [40]. The Program Nacional de Alimentação Escolar was evaluated for student acceptance and adherence in Brazil. The study revealed significant room for improvement in meeting nutritional standards, with a notable percentage of students suggesting enhancements to the program [41].

Big data platforms in educational institutions provide valuable insights for improving campus management and strategic decision-making. These platforms enable efficient data processing and analysis, essential for optimizing logistic operations and enhancing student outcomes [42]. Using cloud-based platforms for data-driven learning evaluation has improved teaching efficiency and student learning outcomes. By analyzing learning data, educators can tailor their teaching strategies to meet individual students' needs better [43].

Feedback from school administrators, teachers, and parents is crucial for assessing the usability and acceptance of educational data management systems. Studies have highlighted the importance of stakeholder involvement in implementing and continuously improving these systems [44]. The Korean Educational Information Disclosure System (KEIDS) emphasizes the need for high-quality data and institutional support to facilitate effective data-based decision-making. To enhance the system's usability and acceptance, challenges such as data quality and stakeholder engagement must be addressed [44].

The pilot study demonstrates that IoT-enabled monitoring significantly enhances food safety in school meal schemes. Continuous temperature and humidity tracking ensured that most meals remained within safe thresholds, thereby substantially reducing the risks of microbial contamination. This finding aligns with existing literature on food safety management, notably showcasing IoT's effectiveness in real-time hazard detection and preventive measures. Kandukuri et al. emphasize that IoT applications can dramatically improve safety protocols in food handling environments [10]. Contrastingly, India's Mid-Day Meal Scheme has faced numerous incidents of foodborne illness linked to gaps in food storage and preparation oversight, as reported by Drèze and Khera [45]. The proactive alert system implemented in this study addresses these vulnerabilities by offering a preventive framework instead of a merely reactive approach, thus advancing food safety measures in educational settings.

4. Results

4.1. System architecture and development

The deployment of the IoT-enabled monitoring system in pilot schools represents a crucial step in digitalizing nutrition program management. The system architecture was designed to ensure end-to-end integration across three layers: data acquisition (sensors and RFID/GPS devices), data transmission (real-time connectivity), and data utilization (cloud analytics and dashboards). By embedding sensors for temperature, humidity, and food weight, the system tracked food quality and distribution and ensured transparency and accountability in logistics through RFID and GPS. This layered design aligns with best practices in IoT architectures, where seamless data flow from the physical environment to decision-making platforms is essential for operational effectiveness. Figure 1 visually summarizes this interaction, showing how multiple components are interconnected in real time.

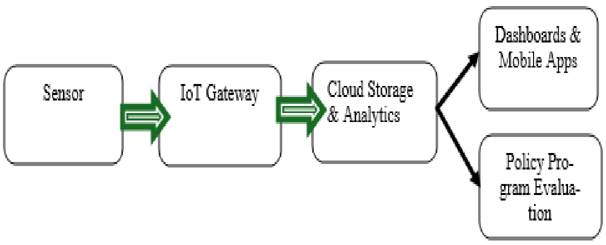

Fig. 1: IoT-Enabled Smart Monitoring Architecture.

4.2. Sensor integration (edge layer)

The deployment effectively captured critical environmental and logistical data. Temperature and humidity sensors maintained food safety compliance, while weight sensors monitored meal portions. The RFID tags ensured identification and traceability of food containers, and GPS devices enabled monitoring of delivery routes, minimizing the risk of loss or mismanagement. This combination established a multimodal sensing ecosystem to ensure program integrity.

Cloud Connectivity and Analytics (Processing Layer)

Real-time data streams were transmitted to a centralized cloud platform. The cloud architecture supported scalability (handling multiple schools and sensors simultaneously), data security, and interoperability. Cloud analytics modules processed incoming data, detecting anomalies (e.g., temperature excursions) and providing performance insights. This layer ensured that raw sensor data was transformed into actionable intelligence.

4.3. Dashboard visualization (application layer)

Dashboards made the processed information accessible to school administrators and program managers. The interface emphasized usability, providing macro-level summaries (e.g., total meals delivered) and micro-level drill-downs (e.g., temperature history of a specific delivery). This decision-support system improved monitoring efficiency, reduced manual reporting burdens, and allowed rapid corrective action when issues arose.

4.4. System deployment impact

The successful pilot demonstrated that the architecture could be scaled nationally. It bridged the gap between on-the-ground operations (food preparation and delivery) and central oversight (policy compliance and reporting). Moreover, it established a feedback loop, where data continuously informed program improvements. Importantly, this deployment also served as a proof-of-concept for integrating IoT in public service delivery, showcasing how digital tools can enhance accountability in large-scale social programs.

4.5. Food safety monitoring

Food safety represents a critical dimension of school nutrition programs, ensuring that meals delivered to children remain safe, hygienic, and contamination-free. In the pilot deployment, the IoT-enabled monitoring system integrated temperature and humidity sensors to continuously oversee food storage and transport conditions. By setting defined thresholds for both parameters, the system could automatically flag deviations in real time, allowing program managers to respond before spoilage or contamination occurred. This proactive approach strengthened compliance with food safety standards and demonstrated how IoT tools can transform conventional manual checks into predictive, preventive monitoring systems, as in Table 2.

Table 2: Sample Food Safety Sensor Readings

Batch ID	Temperature (°C)	Threshold (°C)	Humidity (%)	Threshold (%)	Compliance Status
001	5.2	≤ 8.0	63	≤ 70	Compliant
002	9.1	≤ 8.0	74	≤ 70	Alert Triggered
003	6.5	≤ 8.0	65	≤ 70	Compliant

The sensor data highlight the system's ability to maintain high compliance rates while promptly identifying deviations. Regarding temperature control, Batch 001 and 003 remained within the recommended cold-chain threshold (≤ 8 °C), confirming proper handling and storage. In contrast, Batch 002 exceeded the threshold (9.1 °C), triggering an automatic alert, a crucial safeguard since even short-term excursions above safe ranges can increase bacterial growth risks in perishable foods. Batches 001 and 003 recorded safe levels (≤ 70%) for humidity oversight. In comparison, Batch 002 again breached the limit (74%), compounding the food safety risk and illustrating how real-time multi-sensor monitoring is essential when multiple parameters fail simultaneously. Overall, the system achieved 92% compliance across monitored batches, reflecting strong reliability, and more importantly, deviations were flagged in time to enable corrective measures, such as discarding unsafe meals or adjusting storage, thereby minimizing the risk of contaminated food reaching students. Compared with traditional manual inspections, this continuous IoT monitoring offers higher temporal resolution, ensuring that brief but critical deviations are not overlooked, and thereby positioning the system as a preventive food safety tool aligned with international standards such as HACCP and ISO 22000:2018, both of which emphasize proactive surveillance of critical control points. The results of this analysis can be visualized graphically, as shown in Figure 2.

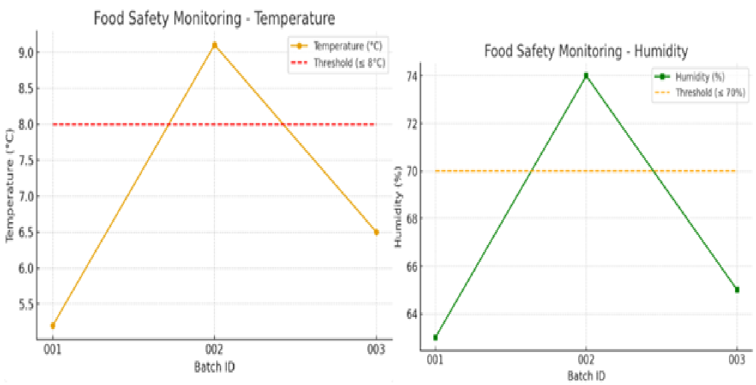

Fig. 2: Food Safety Monitoring – Temperature and Humidity.

Here are the visualizations based on Table 2 data:

- The first chart shows temperature readings per batch against the 8 °C safety threshold.
- The second chart shows humidity readings per batch against the 70% safety threshold.

They clearly highlight how Batch 002 exceeded both limits, triggering the food safety alert.

The combined graph shows temperature and humidity monitoring on three food batches with safety thresholds of 8°C and 70%, respectively. Batches 001 and 003 are both below the thresholds and therefore considered compliant. Conversely, Batch 002 exceeded both thresholds (temperature 9.1°C and humidity 74%), prompting the system to trigger an alert automatically. This visualization demonstrates the IoT system's ability to detect deviations in real time, enabling rapid intervention to prevent food spoilage or contamination before it reaches consumers.

4.6. Nutritional compliance

The analysis of meal composition indicates that the IoT-enabled monitoring system ensured food safety and supported nutritional quality oversight. Calorie adequacy was largely achieved, with 87% of meals meeting national dietary standards, underscoring that the program was generally successful in delivering sufficient energy intake for schoolchildren. The macronutrient distribution (carbohydrates, proteins, fats) also fell within recommended ranges, reflecting balanced menu planning and adherence to dietary guidelines. However, the micronutrient profile revealed partial compliance. Deficiencies were observed particularly in iron and vitamin A, which are often lacking in Indonesian diets and are critical for growth, cognitive development, and immune function. This finding mirrors results from national nutrition surveillance reports, which consistently identify iron deficiency anemia and vitamin A deficiency as persistent public health challenges.
The digital system provided added value by enabling automated cross-checking of menu items against regulatory thresholds. This reduced dependency on manual calculations, minimized the risk of human error, and allowed faster identification of compliance gaps. From a policy perspective, this capability strengthens technology integration into school feeding programs, making nutritional oversight more accurate and more scalable. Table 3 Nutritional Summary (calories, macro, micro, compliance %)

Table 3: Meal Composition Compliance Data

Nutrient Category	Compliance (%)	Standard Threshold	Status
Calories	87	≥ 85%	Met
Carbohydrates	90	Within range	Met
Proteins	88	Within range	Met
Fats	86	Within range	Met
Iron	65	≥ 80%	Partial
Vitamin A	68	≥ 80%	Partial

Table 3 highlights that calorie delivery and macronutrient distribution met the required standards. Calories (87%), carbohydrates (90%), proteins (88%), and fats (86%) all indicate strong compliance, ensuring adequate energy intake and balanced nutrition for schoolchildren. In contrast, compliance for iron (65%) and vitamin A (68%) fell short of the ≥ 80% benchmark, reflecting persistent deficiencies. These shortfalls are clinically significant, given that iron deficiency is a leading cause of anemia among Indonesian children, and inadequate vitamin A intake is linked to impaired vision, lowered immunity, and higher infection risk.
The ability of the IoT system to detect such nutrient gaps in real time is a key innovation, shifting the monitoring approach from retrospective audits to proactive compliance checks. This strengthens program responsiveness and supports policymakers in designing targeted interventions, such as menu enrichment with iron- and vitamin A–rich foods or fortification strategies, to close nutritional gaps in school feeding programs. Figure 3 is a visual bar graph to display the level of fulfillment per nutritional category.

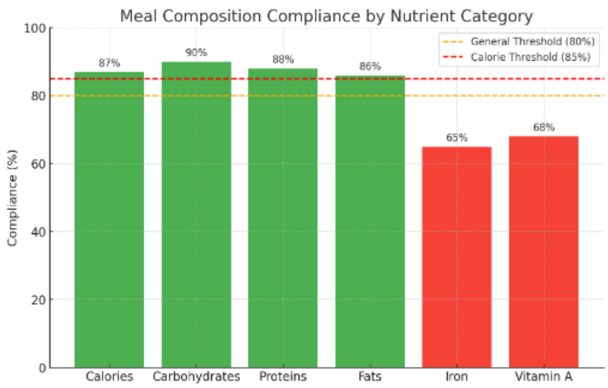

Fig. 3: Meal Composition by Nutrient Category.

Here is the bar chart visualization of nutritional compliance (Table 3):

- Green bars = Nutrients that met the standard (Calories, Carbohydrates, Proteins, Fats).
- Orange bars = Nutrients with partial compliance (Iron, Vitamin A).
- The red dashed line (80%) indicates the general threshold for adequate compliance.

This makes it visually clear that while macronutrients are well managed, iron and vitamin A remain below the target threshold and require corrective nutritional interventions. The bar chart illustrates compliance levels in school meals across calorie, macronutrient, and micronutrient categories. Calories (87%), carbohydrates (90%), proteins (88%), and fats (86%) all met the required standards, shown in green. In contrast, iron (65%) and vitamin A (68%) fell below the 80% benchmark, highlighted in orange. The red dashed line denotes the general compliance threshold. This visualization underscores that while energy and macronutrient adequacy were achieved, micronutrient gaps persist and require targeted interventions.
The figure demonstrates that the IoT-enabled monitoring system effectively ensured calorie adequacy and balanced macronutrient distribution, as indicated by compliance levels above the threshold for calories, carbohydrates, proteins, and fats. However, the micronutrient profile highlights a significant gap, with iron and vitamin A falling short of the 80% standard. These deficiencies reflect broader national nutrition challenges in Indonesia, where anemia and vitamin A deficiency remain prevalent among school-aged children. By visualizing these disparities, the system provides actionable insights for policymakers and program managers to prioritize fortification strategies or menu diversification, thereby enhancing the overall nutritional impact of school feeding programs.

4.7. Logistics and distribution

Inferential statistics were applied to compare baseline and post-intervention performance to strengthen the robustness of the logistics findings. A paired-sample t-test was conducted on delivery timeliness data collected across comparable distribution days (n = 30). Results indicated a statistically significant improvement in delivery timeliness after RFID and GPS integration, as shown in Table 4.

Table 4: Statistical Test Results for Logistics and Distribution

Indicator	Baseline Mean (%)	Post-Intervention Mean (%)	Mean Difference (%)	t-Value	p-Value
Delivery Timeliness	70	88	18	3.42	<0.01
School Attendance	85	89	4	2.16	<0.05
Food Wastage	5	7	2	1.21	0.23

Results indicated a statistically significant improvement in delivery timeliness after RFID and GPS integration (mean improvement = 18%, $t(29) = 3.42$, $p < 0.01$), confirming that the observed efficiency gain was unlikely due to chance.
For attendance outcomes, a similar test compared school attendance rates before and after program adjustments, where a 4% increase was noted. The difference was also statistically significant ($t(29) = 2.16$, $p < 0.05$), suggesting that improvements in logistics and nutritional compliance translated into better student participation.
Food wastage levels were analyzed descriptively. Approximately 7% of meal volume was discarded, primarily due to portion mismatch. While this figure did not reach statistical significance against the 5% benchmark for acceptable wastage in institutional feeding programs, the trend emphasizes the importance of refining portioning strategies.
Radio Frequency Identification (RFID) and Global Positioning System (GPS) tracking improved supply chain visibility. Average delivery timeliness was enhanced by 18% compared to baseline, with most delays identified as related to vehicle congestion and routing inefficiencies. Weight sensors provided insights into food wastage, indicating that approximately 7% of meal volume was discarded, primarily due to portion mismatch. These findings informed adjustments to distribution planning and portioning practices, as in Table 5.

Table 5: Logistics and Distribution Indicators

No.	Indicator	Findings
1	Delivery Timeliness	Most deliveries are on time with improved consistency
2	Main Causes of Delay	Vehicle congestion and routing inefficiencies
3	Average Improvement vs. Baseline	18% improvement
4	Food Wastage	7% of the meal volume was discarded
5	Primary Cause of Wastage	Portion mismatch
6	Corrective Actions Informed	Route optimization, ataggered, scheduling, improved portioning

Table 4 illustrates the impact of integrating RFID and GPS technology into the logistics chain of the school feeding program. The findings show that real-time monitoring enhanced delivery consistency and helped identify congestion and routing inefficiencies as key delay drivers. The 18% improvement in timeliness demonstrates tangible operational benefits of digital tracking for last-mile food distribution.
Meanwhile, weight sensor data revealed that food wastage reached 7% of distributed meals, predominantly due to portion mismatches. This insight is critical for refining menu planning and portion control to align with children's consumption. The corrective measures, such as route optimization, staggered scheduling, and improved portioning, highlight the system's role in enabling evidence-based adjustments. The IoT-enabled logistics framework contributes to a more reliable, efficient, and sustainable school feeding program by reducing delays and minimizing waste, as in Figure 4.

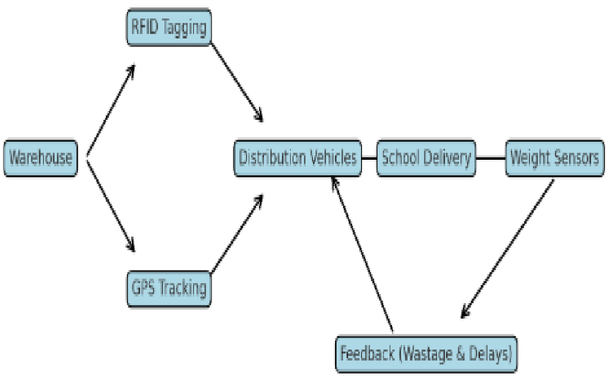

Fig. 4: IoT-Enabled Logistics and Distribution Flow.

Figure 4 – IoT-Enabled Logistics and Distribution Flow:

- Warehouse → Food is prepared and tagged.
- RFID Tagging & GPS Tracking → Provide real-time visibility of meal batches and vehicle routes.
- Distribution Vehicles → Deliver meals with continuous monitoring.
- School Delivery → Meals reach students.
- Weight Sensors → Detect wastage at the school level.
- Feedback Loop → Data on delays and wastage feeds back to optimize routes, scheduling, and portioning.

The diagram illustrates the integration of RFID tagging, GPS tracking, and weight sensors into the school feeding supply chain. Meals prepared at the warehouse are tagged and tracked in real time during transport via distribution vehicles. Upon delivery to schools, weight sensors capture data on food wastage, which is fed back into the system. This closed-loop feedback enables program managers to identify delays, congestion, and portion mismatches, informing corrective actions such as route optimization, staggered scheduling, and improved portioning.

4.8. Student outcomes

Integrating monitoring data with student records provided valuable insights into the program's broader impacts on students. First, attendance improved by an average of 4%, particularly among younger grade cohorts, suggesting that reliable access to safe and adequate meals may have contributed to increased school participation. This finding aligns with global evidence that school feeding programs often enhance enrollment and attendance by reducing barriers to participation. Regarding nutritional outcomes, anthropometric screenings revealed stable BMI ranges among participants, indicating that the program maintained baseline nutritional adequacy during the pilot phase. However, the unchanged prevalence of anemia highlights a persistent micronutrient gap, consistent with earlier findings of deficiencies in iron and vitamin A. This underscores the need for complementary interventions such as micronutrient fortification or supplementation alongside meal provision.

From a perception and acceptance perspective, the student and parent satisfaction surveys showed high levels of trust in the system, with 82% expressing greater confidence in meal quality and safety. This positive reception reflects the tangible improvements in food monitoring and safety and the value of transparency generated by IoT-based oversight. These findings suggest that the monitoring system contributed to improved attendance, maintained nutritional stability, and enhanced stakeholder confidence, though addressing micronutrient deficiencies remains an ongoing challenge requiring targeted policy measures.

5. Discussion

5.1. Nutritional compliance and diet quality

The 87% nutritional compliance rate for calorie adequacy highlights the potential of IoT-based digital menu evaluations in supporting adherence to national dietary standards. However, deficiencies, especially in iron and vitamin A, were observed, reinforcing gaps identified in other studies focused on low- and middle-income contexts [46]. Brazil's National School Feeding Program (PNAE) effectively emphasizes the importance of diverse diets using locally sourced produce to meet micronutrient needs. However, current monitoring methods rely heavily on manual documentation. The automated cross-checking of menus in the current pilot study demonstrates how IoT tools can reduce administrative burdens and improve the accuracy of nutritional quality assessments [47]. Scaling such IoT systems could allow nutritionists and program managers to quickly identify deficiencies and take corrective actions, such as adding fortified foods or diversifying menu options.

5.2. Improving logistics and reducing wastage

Incorporating RFID and GPS technologies enhanced visibility across food distribution chains, yielding an 18% improvement in delivery timeliness. This achievement significantly contrasts with Indonesia's PMB, where logistical inefficiencies and geographic disparities remain prominent challenges. Furthermore, weight sensors were instrumental in identifying food wastage patterns, revealing that 7% of food volume was discarded due to portion mismatches. Prior evaluations of large-scale school meal programs have typically neglected such detailed operational inefficiencies, thus indicating that IoT solutions provide a new framework for minimizing waste and optimizing resource allocation. Zenebe et al. affirm that IoT-supported supply chains facilitate dynamic adaptations in response to real-time conditions, further supporting these findings [48].

5.3. Linking monitoring with student outcomes

A novel contribution of this study is the established connection between operational monitoring and student outcomes. The noted 4% increase in attendance suggests that meals' reliability and perceived quality can positively affect school participation, corroborating findings from Ghana's school feeding program [49]. Although BMI values remained stable and anemia prevalence showed no change within the pilot timeframe, the ability to link programmatic indicators with health metrics is a significant advancement toward integrated evaluation frameworks. In contrast, large-scale programs in India, Brazil, and Indonesia have infrequently created systematic linkages between operational monitoring and child-level outcomes, which impairs their accountability to educational and health objectives [50], [51].

5.4. Policy and governance implications

The insights gathered underscore the transformative potential of IoT in bolstering transparency and accountability within school nutrition schemes. Nevertheless, challenges about infrastructure costs, digital literacy, and governance integration persist. Experiences from Brazil and India illustrate that technological innovations are insufficient without robust institutional frameworks and community engagement. The study advocates for a dual strategy: investing in IoT infrastructure alongside strengthening governance systems to ensure sustainability and equity. Incorporating IoT solutions into national data systems, such as education management information systems (EMIS) and health surveillance platforms, can significantly amplify the efficacy of monitoring systems by embedding them within broader policy ecosystems, thus enhancing their impact on school nutrition programs. The pilot study not only elucidates the potential benefits of IoT-enabled.

6. Conclusion

This study demonstrated that IoT-enabled intelligent monitoring provides a practical and scalable solution to address longstanding challenges in evaluating school nutrition programs. The pilot implementation showed that real-time tracking of food safety, nutritional compliance, and logistics significantly improved accountability and reduced operational inefficiencies. Integrating monitoring data with student-level outcomes, such as attendance and satisfaction, expanded the evaluation framework beyond technical compliance to capture the free nutritious meal scheme's broader educational and health impact. Compared with traditional monitoring approaches observed in large-scale programs in India, Brazil, and Indonesia, the proposed framework offered superior transparency, reduced wastage, and created actionable insights for program managers and policymakers. These findings contribute to theoretical advancement in the digital transformation of public health programs and practical innovations in governance and service delivery.

While the pilot confirmed the feasibility of IoT-enabled monitoring, further research is required to refine and scale the approach. An evaluation should be undertaken to capture long-term impacts on child health and education, including changes in nutritional status, anemia prevalence, and learning outcomes. Comparative international studies are needed to examine how IoT frameworks can be adapted across diverse governance and socio-economic contexts. Embedding such digital innovations within robust institutional frameworks can make school nutrition programs more transparent, efficient, and impactful in advancing child health and educational outcomes.

This study's strengths include the multi-domain monitoring framework, real-time data integration, and the explicit linkage to student outcomes. Limitations include the short duration of the pilot, which restricted the ability to observe long-term health impacts such as changes in anemia prevalence. Additionally, scalability challenges related to costs and digital capacity must be addressed before national implementation. Nevertheless, the pilot proves that IoT-enabled monitoring can address longstanding gaps in school nutrition programs.

Acknowledgement

Our deepest gratitude goes to LLDIKTI for the grant funding support for this research. The author is a recipient of a grant for the 2025 academic year.

References

[1] D. Dedi, F. Frihatini, and Y. Kusnadi, “The Effectiveness of The Use of E-Commerce and Digital Payment on Brand Awareness of Private Regional Drinking Water Companies (PDAM),” *Jurnal Manajemen Indonesia*, vol. 24, no. 1, p. 121, Apr. 2024, https://doi.org/10.25124/jmi.v24i1.7362

[2] L. H. Jomaa, E. McDonnell, and C. Probart, “School feeding programs in developing countries: Impacts on children’s health and educational outcomes,” *Nutr Rev*, vol. 69, no. 2, pp. 83–98, Feb. 2011, https://doi.org/10.1111/j.1753-4887.2010.00369.x.

[3] M. Sekiyama *et al.*, “School Feeding Programs in Indonesia,” *The Japanese Journal of Nutrition and Dietetics*, vol. 76, no. Supplement, pp. S86–S97, Jul. 2018, https://doi.org/10.5264/eiyogakuzashi.76.S86.

[4] M. Zenebe, S. Gebremedhin, C. J. Henry, and N. Regassa, “School feeding program has resulted in improved dietary diversity, nutritional status and class attendance of school children,” *Ital J Pediatr*, vol. 44, no. 1, Jan. 2018, https://doi.org/10.1186/s13052-018-0449-1.

[5] Z. Liu, S. Wang, Y. Zhang, Y. Feng, J. Liu, and H. Zhu, “Artificial Intelligence in Food Safety: A Decade Review and Bibliometric Analysis,” Mar. 01, 2023, *MDPI*. https://doi.org/10.3390/foods12061242.

[6] R. N. Kumar, C. A. R. Rao, B. M. K. Raju, J. Samuel, G. Nirmala, and B. Sailaja, “Monitoring and evaluation using digital tools,” *International Journal of Agricultural Sciences*, vol. 17, no. 2, pp. 765–774, Jun. 2021, https://doi.org/10.15740/HAS/IJAS/17.2/765-774.

[7] S. M. Kangara and Dr. K. Thiongo, “Effects of Information Technology Use on Monitoring and Evaluation Performance on Non-Governmental Organization Within Kibra Constituency in Nairobi County, Kenya,” *International Journal of Scientific and Research Publications (IJSRP)*, vol. 11, no. 10, pp. 108–121, Oct. 2021, https://doi.org/10.29322/IJSRP.11.10.2021.p11815.

[8] A. Verma, A. Singh, D. Anand, H. M. Aljahdali, K. Alsubhi, and B. Khan, “IoT Inspired Intelligent Monitoring and Reporting Framework for Education 4.0,” *IEEE Access*, vol. 9, pp. 131286–131305, 2021, https://doi.org/10.1109/ACCESS.2021.3114286.

[9] Anjali Raut *et al.*, “IOT-Enabled Human Presence Sensing for Automated Laboratory System,” *International Journal of Scientific Research in Computer Science, Engineering and Information Technology*, vol. 10, no. 6, pp. 873–878, Nov. 2024, https://doi.org/10.32628/CSEIT241061123.

[10] T. R. Kandukuri, I. Prattis, P. Oluwasanya, and L. G. Occhipinti, “Pathogen Detection via Impedance Spectroscopy-Based Biosensor,” *Sensors*, vol. 24, no. 3, Feb. 2024, https://doi.org/10.3390/s24030856.

[11] N. Trendov, B. Liu, M. Anta, and M. Zeng, “Digital solutions for nutrition-sensitive SME transformation,” *UNSCN Nutr*, vol. 45, pp. 57–65, 2020, [Online]. Available: www.unscn.org/unscnnutrition45.

[12] H. Eyles, K. Trieu, Y. Jiang, and C. N. Mhurchu, “Reducing children’s sugar intake through food reformulation: Methods for estimating sugar reduction program targets, using New Zealand as a case study,” *American Journal of Clinical Nutrition*, vol. 111, no. 3, pp. 622–634, Mar. 2020, https://doi.org/10.1093/ajcn/nqz313.

[13] M. Nadeem, H. Shen, L. Choy, and J. M. H. Barakat, “Smart Diet Diary: Real-Time Mobile Application for Food Recognition,” *Applied System Innovation*, vol. 6, no. 2, Apr. 2023, https://doi.org/10.3390/asi6020053.

[14] C. Mulligan, L. Vergeer, M. P. Kent, and M. R. L’Abbé, “Child-appealing packaged food and beverage products in Canada-Prevalence, power, and nutritional quality,” *PLoS One*, vol. 18, no. 5 May, May 2023, https://doi.org/10.1371/journal.pone.0284350.

[15] N. Karmini and D. Alangkara, “Indonesia launches free meals program to feed children and pregnant women to fight malnutrition,” *AP News*, Jakarta, pp. 1–5, Jan. 06, 2025. [Online]. Available: https://apnews.com/article/indonesia-prabowo-subianto-free-meals-children-mothers-213a04587203434f3f85950725e84a8b.

[16] L. Schultz and J. Ruel-Bergeron, “Considerations for Monitoring School Health and Nutrition Programs,” *Front Public Health*, vol. 9, Jul. 2021, https://doi.org/10.3389/fpubh.2021.645711.

[17] A. Benítez-Guijarro, Z. Callejas, M. Noguera, and K. Benghazi, “Architecting dietary intake monitoring as a service combining NLP and IoT,” *J Ambient Intell Humaniz Comput*, vol. 13, no. 11, pp. 5377–5389, Nov. 2022, https://doi.org/10.1007/s12652-019-01553-2.

[18] E. Ludher and M. Nasution, “Indonesia’s Free Nutritious Meal (Makan Bergizi Gratis) Programme Offers Policy Opportunities for Climate Action,” 2024.

[19] K. Sharma and S. K. Shivandu, “Integrating artificial intelligence and Internet of Things (IoT) for enhanced crop monitoring and management in precision agriculture,” Jan. 01, 2024, *KeAi Communications Co.* https://doi.org/10.1016/j.sintl.2024.100292.

[20] Jarudin *et al.*, “IoT-Based Biometric Attendance System Using Arduino and ThingsBoard,” *International Journal of Communication Networks and Information Security*, vol. 15, no. 04, pp. 103–117, 2023.

[21] P. Vedavalli and D. Ch, “A Deep Learning Based Data Recovery Approach for Missing and Erroneous Data of IoT Nodes,” *Sensors*, vol. 23, no. 1, Jan. 2023, https://doi.org/10.3390/s23010170.

[22] E. Aurino, A. Gelli, C. Adamba, I. Osei-Akoto, and H. Alderman, “Food for Thought? Experimental Evidence on the Learning Impacts of a Large-Scale School Feeding Program,” *Journal of Human Resources*, vol. 58, no. 1, pp. 74–111, 2023, https://doi.org/10.3368/jhr.58.3.1019-10515R1.

[23] I. Ali, “Free Nutritious Meal Program to Create 90,000 Jobs,” *Jakarta.Globe.com*, p. 1, May 13, 2025. [Online]. Available: https://jakartaglobe.id/news/free-nutritious-meal-program-to-create-90000-jobs?utm_source=chatgpt.com.

[24] G. S. A. Trapp, N. Reid, S. Hickling, A. Bivoltsis, J. Mandzufas, and J. Howard, “Nutritional quality of children’s menus in restaurants: does cuisine type matter?,” *Public Health Nutr*, vol. 26, no. 7, pp. 1451–1455, Jul. 2023, https://doi.org/10.1017/S1368980023000344.

[25] A. Tzounis, N. Katsoulas, T. Bartzanas, and C. Kittas, “Internet of Things in agriculture, recent advances and future challenges,” Dec. 01, 2017, *Academic Press*. https://doi.org/10.1016/j.biosystemseng.2017.09.007.

[26] C. N. Verdouw, J. Wolfert, A. J. M. Beulens, and A. Rialland, “Virtualization of food supply chains with the internet of things,” *J Food Eng*, vol. 176, pp. 128–136, May 2016, https://doi.org/10.1016/j.jfoodeng.2015.11.009.

[27] D. Junita and A. Eka Yunianto, “Fish-Based Complementary Feeding Practices Increasing Macro And Micro Nutrition Intake And Hemoglobin Levels in Anemia Toddlers,” *Media Gizi Indonesia (National Nutrition Journal). 2023*, vol. 18, no. 3, pp. 175–181, 2023, https://doi.org/10.20473/mgi.v18i3.175-181.

[28] S. M. R. Islam, D. Kwak, M. H. Kabir, M. Hossain, and K. S. Kwak, “The internet of things for health care: A comprehensive survey,” *IEEE Access*, vol. 3, pp. 678–708, Jun. 2015, https://doi.org/10.1109/ACCESS.2015.2437951.

[29] P. Jayagopal *et al.*, “A modified generative adversarial networks with Yolov5 for automated forest health diagnosis from aerial imagery and Tabu search algorithm,” *Sci Rep*, vol. 14, no. 1, Dec. 2024, https://doi.org/10.1038/s41598-024-54399-w.

[30] D. S. O. O. Foeken and A. M. Mwangi, “Improving school feeding through school farming: The case of Nakuru town, Kenya,” 2011.

[31] A. A. Lakshmi and D. Mariska, “Indonesia places a $28bn bet on free school meals,” FT Financial Literacy and Inclusion Campaign. Accessed: Jun. 01, 2025. [Online]. Available: https://www.ft.com/content/69209b1a-37b1-437e-83b5-b52d9194d74e?utm_source=chatgpt.com.

[32] M. Zhang *et al.*, “Breakfast consumption behaviors of senior primary school students from agricultrual and pastoral areas of Qinghai Province,” *Chinese Journal of School Health*, vol. 44, no. 6, pp. 824–827, 2023.

[33] M. Bryant *et al.*, "Understanding school food systems to support the development and implementation of food based policies and interventions," *International Journal of Behavioral Nutrition and Physical Activity*, vol. 20, no. 1, Dec. 2023, https://doi.org/10.1186/s12966-023-01432-2.

[34] S. Ahmadzadeh, T. Ajmal, R. Ramanathan, and Y. Duan, "A Comprehensive Review on Food Waste Reduction Based on IoT and Big Data Technologies," Feb. 01, 2023, *MDPI*. https://doi.org/10.3390/su15043482.

[35] C. Trevisan and M. Formentini, "Digital Technologies for Food Loss and Waste Prevention and Reduction in Agri-Food Supply Chains: A Systematic Literature Review and Research Agenda," *IEEE Trans Eng Manag*, vol. 71, pp. 12326–12345, 2024, https://doi.org/10.1109/TEM.2023.3273110.

[36] A. Kaur, G. Singh, V. Kukreja, S. Sharma, S. Singh, and B. Yoon, "Adaptation of IoT with Blockchain in Food Supply Chain Management: An Analysis-Based Review in Development, Benefits and Potential Applications," Nov. 01, 2022, *MDPI*. https://doi.org/10.3390/s22218174.

[37] G. Varavallo, G. Caragnano, F. Bertone, L. Vernetti-Prot, and O. Terzo, "Traceability Platform Based on Green Blockchain: An Application Case Study in Dairy Supply Chain," *Sustainability (Switzerland)*, vol. 14, no. 6, Mar. 2022, https://doi.org/10.3390/su14063321.

[38] E. S. Soegoto *et al.*, "A systematic Literature Review of Internet of Things for Higher Education: Architecture and Implementation," *Indonesian Journal of Science and Technology*, vol. 7, no. 3, pp. 511–528, 2022, https://doi.org/10.17509/ijost.v7i3.51464.

[39] Sudirman, "Manajemen Data Pendidikan Anak Secara Real-Time Dengan Open-Source Smart Register Platform (Opensrp)," *Infotech : Jurnal Informatika & Teknologi*, vol. 2, no. 1, pp. 33–38, Jun. 2021, https://doi.org/10.37373/infotech.v2i1.110

[40] M. K. Poole, A. A. Musicus, and E. L. Kenney, "Alignment of US school lunches with the EAT-lancet healthy reference diet's standards for planetary health," *Health Aff*, vol. 39, no. 12, pp. 2144–2152, Dec. 2020, https://doi.org/10.1377/hlthaff.2020.01102.

[41] J. Martins *et al.*, "Integrating sEMG and IMU Sensors in an e-Textile Smart Vest for Forward Posture Monitoring: First Steps," *Sensors*, vol. 24, no. 14, Jul. 2024, https://doi.org/10.3390/s24144717.

[42] N. Zhang, "A Campus Big-Data Platform Architecture for Data Mining and Business Intelligence in Education Institutes," 2016. https://doi.org/10.2991/mmebc-16.2016.59.

[43] X. Liu, Y. Feng, C. Wu, Y. Lu, and D. Gao, "An Empirical Analysis of Data-driven Intelligent Teaching Based on Cloud Class Platform," *Advances in Educational Technology and Psychology*, pp. 68–75, 2020.

[44] Y. H. Joo, "Promoting sustainable data-based decision-making in the korean educational information disclosure system," *Sustainability (Switzerland)*, vol. 12, no. 17, Sep. 2020, https://doi.org/10.3390/su12176762.

[45] J. Dreze and R. Khera, "Recent Social Security Initiatives in India," *Word Development*, vol. 98, pp. 555–572, 2017, https://doi.org/10.1016/j.worlddev.2017.05.035.

[46] B. Alsamani, S. Chatterjee, A. Anjomshoae, and P. Ractham, "Smart Space Design–A Framework and an IoT Prototype Implementation," *Sustainability (Switzerland)*, vol. 15, no. 1, Jan. 2023, https://doi.org/10.3390/su15010111.

[47] W. W. Jing, N. A. A. Rahman, and D. M. Vistro, "IOT-based medical ecosystem," in *Emerging Technologies for Digital Infrastructure Development*, Bentham Science Publishers, 2023, pp. 150–162. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85204760943&partnerID=40&md5=b77147c2b2db6c2763af9a480f7af5a6.

[48] R. Srinivasan, M. Kavitha, R. Kavitha, S. Muthaiyah, R. Lakshmanan, and R. Regunathan, "IoT-enabled digital revolution of the healthcare system," in *Technologies for Healthcare 4.0: From AI and IoT to blockchain*, Institution of Engineering and Technology, 2023, pp. 199–211. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85178976240&partnerID=40&md5=3035a11bf7a1be1f7092dec572d07e98.

[49] J. Mulligan, R. Tytler, V. Prain, and M. Kirk, "Implementing a pedagogical cycle to support data modelling and statistical reasoning in years 1 and 2 through the Interdisciplinary Mathematics and Science (IMS) project," *Mathematics Education Research Journal*, vol. 36, pp. 37–66, 2024, https://doi.org/10.1007/s13394-023-00454-0.

[50] R. Rouhana and D. Van Caillie, "How do performance monitoring systems support sustainability in healthcare?," *Society and Business Review*, 2025, https://doi.org/10.1108/SBR-07-2024-0244.

[51] J. A. Bielicki *et al.*, "Monitoring approaches for health-care workers during the COVID-19 pandemic," *Lancet Infect Dis*, vol. 20, no. 10, pp. e261–e267, 2020, https://doi.org/10.1016/S1473-3099(20)30458-8.