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SSA: Smart Sugarcane Agriculture Utilizing the Zachman Framework for Advanced Enterprise Architecture

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Abstract. Enterprise Architecture (EA) is now indispensable for organizations to manage their business operations, data, infrastructure, and ICT systems. Sugarcane agriculture, using EA, is crucial for augmenting production efficiency for both sugarcane cultivators and researchers. Nevertheless, the sector faces considerable challenges in adopting EA, such as incomplete implementation, insufficient knowledge of technological advancements, suboptimal usability of architectural frameworks, lack of proper documentation, and slow service delivery. Additionally, there is no clear standardization for operating procedures. Some research has tried to tackle these challenges but often fails to systematically outline the steps and requirements for designing an enterprise architecture for SSA. This study aims to utilize EA for the Smart Sugarcane-Agriculture system, emphasizing the unique characteristics of agricultural fields. This research has developed a comprehensive EA model by employing the Zachman Framework (ZF) as an Enterprise Architecture Planning (EAP) methodology. The outputs include mapping the EA model, a list and classification of critical success factors, an EA service and information, a solution concept diagram, and an EA business process modelling to develop SSA. This research helps identify and select the appropriate EA framework for Smart Sugarcane Agriculture, assisting local governments and stakeholders in prioritizing critical factors in developing SSA EA.

1 INTRODUCTION

The plantation sub-sector, contributing about 3.76% to GDP in 2022, is a key part of the Agriculture, Livestock, Hunting, and Agricultural Services sectors. It supplies raw materials to industry, provides significant employment, and generates foreign exchange. In Indonesia, sugarcane, grown on around 490,000 hectares, is crucial for the sugar industry, supporting many farmers and workers (1). However, weather variability, pests, and soil fertility issues affect yields and costs. Recent interest in intelligent agricultural technologies aims to improve productivity and sustainability in sugarcane farming. Despite rising domestic sugar consumption, production falls short of demand, and the government targets self-sufficiency to enhance food security.

EA is vital for optimizing sugarcane agriculture operations, data management, infrastructure, and technology. Its adoption improves electronic service efficiency but faces challenges like partial implementation, alignment issues, limited technological understanding, slow service delivery, usability problems with frameworks, and unclear standardization. Overcoming these challenges is essential for using EA to boost sustainability, increase sugarcane production, and enhance operational efficiency. Studies addressing these challenges include Digital Enterprise Architecture for Advanced Sugarcane Agriculture: Implementing e-agriculture using ICT enhances farming practices through advanced technologies such as educational plant environments, IoT, AI, precision agriculture, and data analytics (2,3). ICT and digital tools can potentially revolutionize extension and advisory services. They can transform the methods used by extensionists in their work and alter the organization and staffing of extension institutions (4). These technologies enable real-time monitoring of environmental conditions, efficient resource application, predictive disease modeling, and improved crop yield and quality (5,6). Green Enterprise Architecture facilitates the integration of sustainable practices in SSA systems, addressing challenges like weather fluctuations and pest control in sugarcane farming (7). Digital farming and agriculture technologies promise increased efficiency and profitability, ensuring a sustainable and productive future for the sugarcane industry (8–13). Agricultural Social Networks foster collaboration and knowledge sharing among farmers, enhancing the adoption of innovative farming practices (14,15). The TOGAF Framework provides a structured approach to align technology integration with business objectives in agriculture, optimizing operational processes and resource management (16,17). Enterprise Modeling (EM) frameworks support designing and implementing efficient agricultural systems, improving decision-making and operational effectiveness in sugarcane farming (18).

This research addresses the underexplored area of agricultural EA—implementing the Zachman Framework (ZF) as an Enterprise Architecture Planning (EAP) methodology to implement EA designed explicitly for Smart Sugarcane Farming. Apart from EAP, it also contributes to output, which includes EA model mapping, list and classification of critical success factors, EA services and information, solution concept diagrams, and EA business process modeling to develop SSA. This contributes to identifying and adopting an appropriate EA framework to improve agricultural practices in districts in Indonesia, supporting local governments and stakeholders in prioritizing key factors for Smart Sugarcane Farming EA.

2 LITERATURE REVIEW

2.1 Smart Systems and Enterprise Architecture in Agriculture

Data's value in agriculture lies in supporting farmers, boosting income, advancing food production, and creating digital profiles and strategies (19). Accurate and timely data is crucial for implementing intelligent systems in agriculture. Recent advancements have enhanced sugarcane farming globally, with Indonesian initiatives addressing local challenges through technology. This includes educating students, teachers, and farmers on indoor plant ecosystems and promoting smart agriculture through technology. AI improves predictive analytics and automated decision-making, while Extended Reality (XR) offers immersive

training, bridging the technology gap. Studies on AR/VR highlight their use in education across various fields (20–23). Technological innovations like precision agriculture equipment require enhanced farmer training to maximize their practical use and agronomic benefits (15).
Research on enterprise architecture highlights its role in manufacturing by integrating IT systems for comprehensive data analytics and mobile information, enhancing quality, process improvement, and organizational flexibility (24). It also integrates environmental sustainability into digital transformations, emphasizing the need for further research in agriculture (7). Boosting agricultural productivity relies on modern technologies, resource access, functioning markets, infrastructure, and supportive policies (6). ICTs improve productivity and sustainability, addressing challenges like water scarcity and soil degradation, crucial for food security through accessible information via e-agriculture frameworks (5). In Indonesia, where many work as farmers, developing an Integrated Agriculture Information System (IAIS) using TOGAF is critical to enhancing productivity (16,17). The Enterprise Modelling framework tailored for arable farms improves business integration and system design efficiency [18]. Implementing SSA in agriculture integrates advanced environmental modeling and remote sensing technologies (10,11,25,26).

2.2 The Zachman Framework

The Zachman Framework is a foundational taxonomy that aids organizations in organizing complex systems from multiple perspectives (26,27). By defining various viewpoints and their interrelationships, it enhances clarity and transparency in enterprise architecture. This structured approach supports comprehensive analysis and decision-making throughout an enterprise system's lifecycle, from design to maintenance. Ultimately, it helps organizations navigate modern information system complexities and optimize their architecture for greater agility, efficiency, and innovation in a rapidly evolving digital landscape.

3 METHODOLOGY

The research method employed in this study involves the comprehensive development of the Zachman Framework. The Zachman Framework is a structured approach that focuses on classifying and organizing various representations of a company to facilitate the development of future systems. This framework ensures a coherent and organized pathway for system development by systematically categorizing different aspects of the organization. The detailed stages of Enterprise Architecture Planning (EAP) development, guided by the principles of the Zachman Framework, can be seen in the following Fig. 1. This figure outlines each step in the process, highlighting the systematic approach to achieving an integrated and efficient system architecture for the SSA sector.

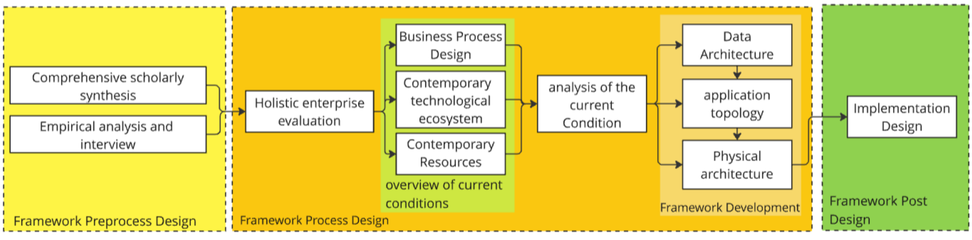


Fig. 1. Research Methodology Structure

The research process for implementing an SSA system involves several key stages. First, a comprehensive scholarly synthesis is conducted to search for materials and literature that support and expand upon the theory and initial discussion of the chosen topics. This foundational step ensures a comprehensive understanding of the subject matter. Next, data acquisition occurs through two primary methods: empirical analysis and interviews. The empirical analysis involves a direct and online examination of research locations to gather relevant activities, documents, and other necessary elements. These empirical analyses were conducted directly in five cities and online in twenty-seven cities, all within the East Java province of Indonesia. Additionally, interviews are conducted with IT-related district officials, employees, and other research-related parties to gather in-depth insights and data. The holistic enterprise evaluation phase focuses on identifying rules and guidelines related to enterprise architecture planning for SSA. This phase lays the groundwork for the structured development of the system. An overview of current conditions is then undertaken based on ongoing enterprise analysis. This includes business process modeling, which involves listing the current business processes and developing a business model based on the company's organizational structure. The current systems and technology are also identified and documented to understand the existing infrastructure and technological needs. Contemporary and current resource conditions are assessed and documented to understand their capabilities, gaps, efficiency levels, and the resources needed. The current review results are analyzed using Porter's Five Forces Analysis. This analysis helps review the company's condition and assess the necessary changes for enterprise improvement. The architectural model design phase involves several sub-steps. Data architecture focuses on identifying and designing architectures according to the needs of data entities within the company's business processes, using CDM (Conceptual Data Model) and PDM (Physical Data Model) to describe inter-entity relations. Application architecture involves identifying and listing applications that can be utilized during business processes. Technology architecture defines the technology required to run the planned applications effectively. Finally, an implementation plan is developed. This plan outlines the various architectures designed according to the company's needs, ensuring a systematic and organized approach to implementing the SSA system.

4 RESULTS AND DISCUSSION

4.1 Analysis of Current Systems

This research performed Porter's Five Forces Analysis to analyze the current system analysis. Traditional farming methods and agricultural practices dominate the current industry landscape. Suppliers of agricultural inputs such as seeds, fertilizers, and equipment wielded significant power due to limited alternatives and technological advancements. This influenced enterprise architecture (EA) strategies, which focused on optimizing procurement systems, managing supplier relationships, and ensuring reliable supply chains to minimize costs and enhance operational efficiency. Farmers and agricultural organizations faced limited bargaining power, constrained by fewer alternative technologies and solutions available in the market. EA frameworks aimed to improve productivity, optimize yield through conventional farming practices, and control costs to maintain competitiveness and profitability. Substitute products or services in agriculture were minimal, primarily revolving around different crop varieties or labor-intensive methods. EA strategies thus concentrated on improving soil management, crop rotation practices, and operational efficiencies to mitigate risks associated with substitutes and ensure sustainable agricultural practices. Competition among agricultural enterprises was driven by factors such as land availability, crop prices, and government policies. EA frameworks supported by agrarian cooperatives, trade associations, and regulatory measures sought to stabilize market conditions, optimize production processes, and foster industry sustainability. Table 1 describes the result of Porter's Five Forces Analysis.

Table 1. Current Condition Analysis

Porter's Five Forces	*Analysis*	*Impact on EA*
Threat of New Entrants	Advanced technology raises barriers to entry, requiring high investment and specialized knowledge.	Reduces threat by deterring new entrants unable to match technology, maintaining a competitive edge.
Bargaining Power of Suppliers	Suppliers wield significant power due to specialized products and services.	Farmers negotiate terms but risk dependency on specific providers.
Bargaining Power of Buyers	Improved crop quality and yield empower farmers in price negotiations.	Increases bargaining power, potentially raising sugarcane prices.
Threat of Substitute Products	Technology boosts sugarcane efficiency, reducing the threat of substitutes.	It makes sugarcane more competitive against substitutes like biofuels.
Industry Rivalry	Technology-driven productivity intensifies competition among farmers.	Promotes innovation to maintain market position amidst fierce competition.

4.2 The EA Model proposed for SSA using the Zachman Framework

The Zachman Framework organizes system architecture facets essential for integrating various technologies in agricultural applications. It categorizes components into distinct viewpoints for comprehensive organization and alignment. The proposed SSA architecture model, developed using the Zachman Framework, shows how stakeholder perspectives, processes, and data align to support their interests, as detailed in Fig 2. This framework emphasizes the importance of coordinating and collaborating among government agencies, institutions, and stakeholders to align with the SSA concept. Fig 2 systematically maps data and information artifacts within a structured framework, detailing relationships among SSA's foundational components.

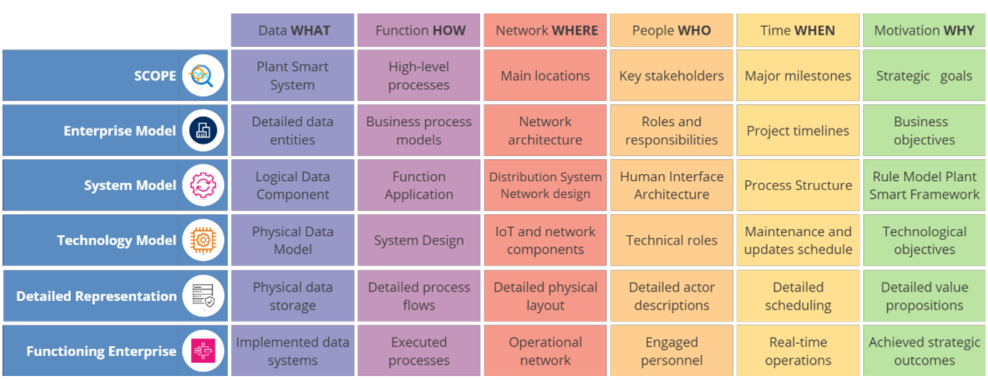


Fig 2. Proposed Enterprise Architecture Model Of SSA With The Zachman Framework

4.3 Proposed List and Classification of Critical Success Factor(CSF) of SSA

As the foundation for developing the SSA architecture, the Critical Success Factors (CSFs) are essential for creating the SSA architecture, as shown in Fig. 3. Key technological CSFs include real-time data acquisition, robust connectivity, and a resilient, scalable data architecture. Regular updates and maintenance are crucial for system reliability and strategic alignment. Clearly defined technical roles and continuous skill enhancement are necessary for effective implementation and maintenance. Transparent procedures, precise scheduling, and streamlined bureaucratic processes ensure timely adherence to business models. Accurate data management, user-friendly interfaces, and robust IT governance frameworks support efficient operations. Aligning activities with strategic goals, defining business objectives, and monitoring outcomes are vital for success. Engaging stakeholders, setting milestones, and promoting collaboration ensure the system's functionality and sustainability.

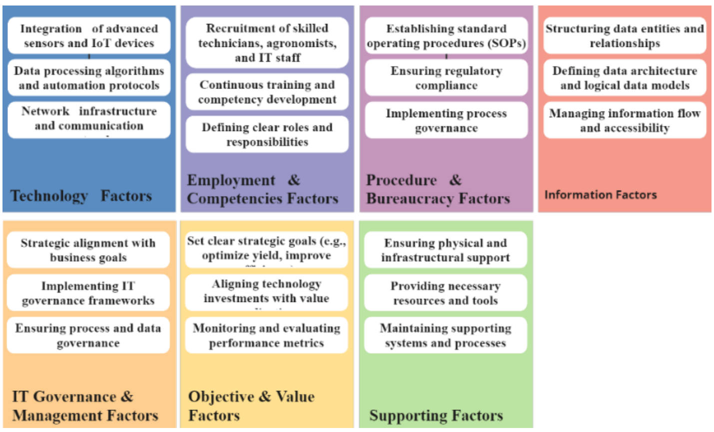
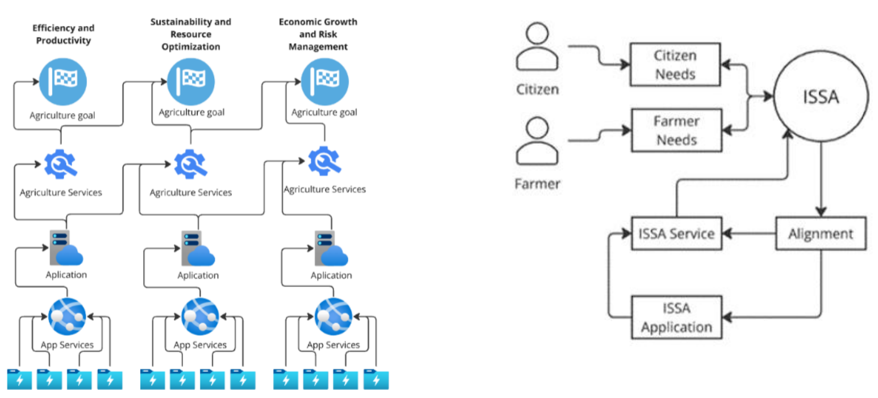


Fig 3. Critical Success Factor(CSF) of SSA

4.4 Service and Information to Support SSA

Aligning the service and information layers in SSA architectures is essential. Fig. 4 (a) illustrates how aligning agriculture services with information systems helps meet agricultural strategies and goals, addressing farmers' and citizens' needs.



(a) (b)

Fig 4. (a) Concept Service and Information of SSA; (b) Correlation need and process translation in Service and Information of SSA.

SSA should focus on a strategic plan and innovative solutions for individuals, communities, and businesses. Agriculture services must prioritize citizen needs over organizational structures, promoting data-driven decision-making and partnerships with technology providers. A citizen-centric approach to service design and delivery is crucial for achieving efficiency, productivity, sustainability, and economic growth. Customer support and prioritizing citizens' interests are paramount. The model shows how citizens' needs drive SSA strategies by aligning agricultural services and information systems. The goal is to align agricultural services with information systems to meet community and farmers' needs. SSA must create a strategic plan and innovative solutions designed to meet the needs of the community and farm sector. Distributed input will inform agricultural services and related applications, which will be processed to derive rules, data, functions, and applications (3,19). These processed inputs will generate outputs that directly address and fulfill the identified needs, achieving SSA's goals. The sequence of correlations between needs, processes, and outcomes is crucial for successfully implementing SSA's objectives, ensuring efficient services align with community and agricultural stakeholders' requirements (27). Fig. 4 (b) illustrates how needs translate into processes and outcomes, serving SSA's goals.

4.5 Solution Concept Diagram

The solution for system development involves a comprehensive Solution Concept Diagram comprising three distinct layers: Front Office, Middle Office, and Back Office. The Front Office layer is the users' primary point of interaction, encompassing portals developed using advanced web and mobile technologies (28). This layer is designed to provide a user-friendly interface, facilitating seamless access and interaction with the system's various features and services. Fig. 5 provides a complete and detailed illustration of the Solution Concept Diagram, showcasing the intricate interplay between the multiple layers and components.

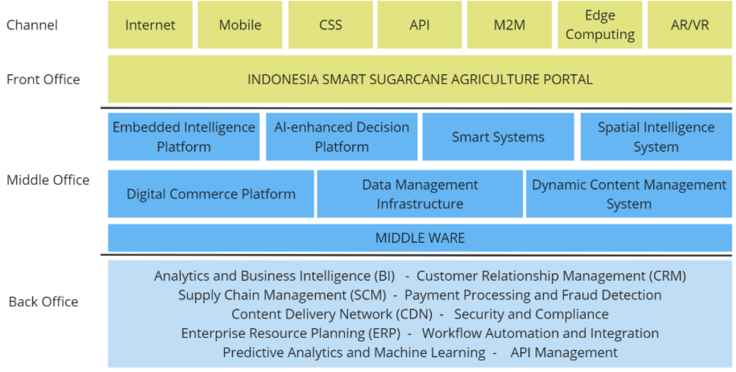


Fig 5. Solution Concept Diagram of SSA

The Middle Office is divided into two parts. The first part interfaces with channels and includes IoT and AI systems: Smart Systems for automated processes, Spatial Intelligence Systems for geographical data analysis, Embedded Intelligence Platforms for integrating AI into hardware, and AI-enhanced Decision Platforms for advanced decision-making support. The second part focuses on data visualization and management, utilizing a Digital Commerce Platform for online activities, a Data Management Infrastructure for handling large data volumes, and a Dynamic Content Management System for delivering content based on user interactions (29).

The Back Office layer supports backend operations with Analytics and Business Intelligence systems for actionable insights, Customer Relationship Management (CRM) systems for customer interactions, and Supply Chain Management (SCM) systems for managing goods and services. It also includes Payment Processing and Fraud Detection Systems, a Content Delivery Network (CDN) for reliable content delivery, Security and Compliance systems, Enterprise Resource Planning (ERP) systems for integrated business management, Workflow Automation tools, Predictive Analytics and Machine Learning systems, and API Management tools for smooth software integration. These components ensure efficient and effective backend operations and infrastructure for advanced system functionalities.

4.6 Main and Sub-Activity Process Modeling

The activity process modeling in SSA is implemented in three parts: intelligent government, intelligent economy, and mobility, followed by smart people. Fig. 6 shows the complete concept of the SSA's main activity.

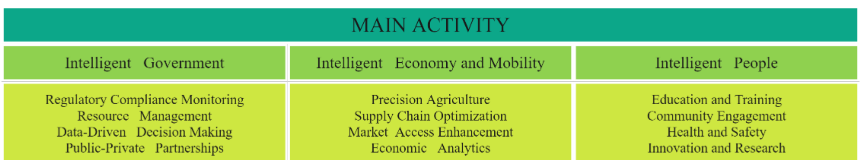


Fig 6. The SSA's main activity

The main activity for Intelligent Government focuses on improving regulatory compliance, resource management, data-driven decision-making, and public-private partnerships. It employs real-time sensors and dashboards for monitoring environmental parameters, with automated reporting and detailed logs for compliance verification. Innovative irrigation systems, precision agriculture, and renewable energy sources optimize resource management. A centralized data repository, AI, and machine learning provide insights for policy-making. Public-private partnerships encourage innovation through joint R&D, grants, and pilot projects.

The main activity for Intelligent Economy and Mobility emphasizes precision agriculture, supply chain optimization, market access enhancement, and economic analytics. Sensor networks and AI optimize farming schedules and automate crop management. IoT-enabled logistics and real-time inventory monitoring ensure efficient transportation and storage. Digital platforms for direct sales, integrated payment gateways, and market analysis tools enhance market access. Data analytics track agricultural performance and identify growth opportunities.

The main activity for Intelligent People prioritizes education, community engagement, health and safety, and innovation. Online courses, workshops, and helplines support sustainable farming education. Online forums, community events, and awareness campaigns promote collaboration. Health and safety systems provide real-time hazard alerts and access to healthcare. Partnerships with academic institutions and grants support the development and testing of new farming technologies.

5 Conclusion

This research has produced the Mapping Enterprise Architecture Model, a list and classification of Critical Success Factors, EA services and information, and Business Process Modeling from SSA Development. The architectural design results will provide a foundation for further research into developing information systems architecture for SSA. In creating this SSA architecture model, it is essential to accommodate all stakeholder needs to ensure comprehensive modeling of SSA development requirements. Building on this research, it is necessary to design Data Architecture Modeling, Information Systems Architecture

Modeling, Physical Architecture Modeling, and an Application Portfolio of innovative modeling to achieve a more detailed and accurate system architecture design.

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