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An Architecture Framework for Supply Chain Management Systems Integrated with Supervisory Control and Data Acquisition Functionality

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Abstract. Supply chains face pressing challenges like production delays that hamper responsiveness and revenue. While information system integration attempts enhancing visibility, the potential of industrial Supervisory Control and Data Acquisition (SCADA) merits exploration within modern supply chain architecture. This study proposes integrating SCADA technology to address delays in material supply and improve coordination across procurement, warehousing, and logistics activities. An architecture framework leveraging TOGAF methodology outlines integrating SCADA monitoring and control functionalities within supply chain databases and applications. By theoretically linking SCADA with inventory and production systems, the research conceptualizes an enhanced architecture that strengthens accountability, automates processes, and allows rapid response to disruptions. Quantitative evaluation is warranted to validate advantages, but archival analysis suggests this fusion bears promise in optimizing future supply chains.

Keywords: Supply Chain Management, SCADA integration, Production Delays.

1. Introduction

In the era of globalization and intensified competition, Supply Chain Management (SCM) has become an important aspect of the success of companies in various sectors. High demand for products and services drives companies to maximize their operations to efficiently respond to market changes. However, the complexity of modern supply chains brings challenges in integrating and coordinating various activities, from procurement to distribution (Ross, 2004).

In the production industry, the supply chain has several key components that are interrelated. These include raw material procurement, production processes, storage, and distribution of finished products. One of the main challenges is the delay in preparing production materials. This can be caused by several factors, such as late delivery from suppliers, lack of coordination between departments, and an imbalance between demand and supply (Yap & Ramli, 2017). These delays not only hold the distribution to customers but also potentially reduce the company's trust and revenue (Heikkila, 2002). The company suffered losses due to delays in the delivery of production material including resulting in unproductive machinery and labor, unexpected production costs, delays in delivery to customers, uncertainty in planning, damage to the company's reputation, and the possibility of additional costs that must be borne to speed up the production process.

Recent research has identified these issues and aims to solve these problems related to delay of material (Paul & Torabi, 2019). However, the potential of integrating Supervisory Control and Data Acquisition (SCADA) technology with Supply Chain Management system is still not fully explored (Carmona, Benitez, & Gervacio, 2016). SCADA which has capabilities in supervision, control, and automation of production processes (Merchan, Peralta, & Salinas, 2017) has the opportunity to overcome delays in production materials in the supply chain.

Compared to previous research that explored issues such as adaptability to new technologies and high implementation costs in the development of Supply Chain Management Systems (Gunasekaran & Ngai, 2004) and explored the effectiveness of SCADA in the production process (Phuyal & Bista, 2020). This research focuses on how SCADA integration can solve production material delays and enhance operational performance in the supply chain.

This research proposes an Architecture Framework for Supply Chain Management Systems Integrated with Supervisory Control and Data Acquisition, to solve the problem of production material delays. This Research focuses on how Supervisory Control and Data Acquisition (SCADA) integration improves real-time visibility in the supply chain, particularly in mitigating and predicting production material delays, and what are the key components and functions required in an Architectural Framework to integrate SCADA with existing Supply Chain Management Systems.

This research aims to balance the demand and supply of production materials in the supply chain and enhance the effectiveness of the coordination between departments and stock visibility. Additionally, this research aims to develop practical and innovative solutions to overcome production delays by integrating SCADA into supply chain management, which is expected to improve the competitiveness of the company.

2. Related Work

2.1. Supply Chain Management

Supply chain management is a relationship between suppliers and customers to deliver highly optimized values to customers at a fairly low cost but provide overall supply chain benefits (Christopher, 2011). The focus of SCM is relationship management to create optimal results and benefits for all parties in the supply chain management chain. in the supply chain, several main stakeholders are companies that have an interest in the flow of goods, the main players are suppliers, manufacturers, distribution, retail outlets, and customers (Indrajit & Djokopranoto, 2003).

Supply chain strategy leads to long-term planning to create products that are cheap, quality, timely, varied, and support the supply chain to achieve predetermined strategic goals. Objectives can be achieved through companies must have the ability to operate efficiently, create high product quality, respond quickly to consumer needs, be flexible, and innovative in responding to changes that occur within the company (Anatan & Ellitan, 2008).

2.2. Information System

Information system is a system in the organization that meets the needs of daily transaction processing that supports the managerial function of organizational operations. Information systems in the business world are very helpful in the supply chain process and sustainability in the business world. Information systems are applications within an organization to support the information needed by all levels of management. It is known that information is very important for organizations in managing decision-making (Sutabri, 2003).

An integrated system is capable of providing useful information to its users, or an integrated system or human-machine system, to provide information to support operations, and management in an organization. These systems utilize computer hardware and software, manual procedures, management models, and databases. Information systems consist of components called building blocks, namely input blocks, model blocks, output blocks, technology blocks, database blocks, and control blocks. As a security system, each of these blocks interacts with each other to form a single unit to achieve its goals (Jogiyanto, 2005).

2.3. The Open Group Architecture Framework (TOGAF)

TOGAF provides a detailed method for building, managing, and implementing enterprise architecture and information systems called the Architecture Development Method (ADM) (Riwanto, 2019). ADM is a generic method that contains a set of activities used in modeling the development of enterprise architecture. This method can also be used as a guide or tool for planning, designing, developing, and implementing information systems architecture for organizations.

TOGAF ADM is a flexible method that can identify a wide variety of modeling techniques used in the design, because this method can be adapted to changes and needs during the design. TOGAF ADM also states a clear vision and principles on how to do the development of enterprise architecture, these principles are used as a measure in assessing the success of enterprise architecture development by the organization. The first step that needs to be considered when implementing TOGAF ADM is to define the preparations, namely by identifying the context of the architecture to be developed, second is to define the strategy of the architecture and determine the parts of the architecture to be designed, starting from business architecture, information systems architecture, technology architecture, and determine the capabilities of the architecture to be designed and developed.

2.4. SCADA

SCADA (Supervisory Control and Data Acquisition) is a system that can perform supervision, control, and data acquisition of a plant. Supervisory control in control terminology often refers to indirect control or emphasizes more on coordination and supervision functions, in other words, the main control is still held by the PLC while the control in SCADA is only coordinative and secondary. Data acquisition of SCADA systems refers to the methods used to access and control information or data from controlled and monitored equipment. The data is then accessed forwarded to the telemetry system ready for transfer to different places. It can be analog and digital information collected by sensors, such as flowmeter, and ammeter, it can also be data to control equipment such as actuators, relays, valves, and motors. Supervisory control and data acquisition (SCADA) is a control system architecture comprising computers, networked data communications, and graphical user interfaces for high-level supervision of machines and processes. It also covers sensors and other devices, such as programmable logic controllers, which interface with process plants or machinery. (Tamar, 2023).

2.5. SCADA-SCM Integration

SCADA technology has great potential to bring deeper visibility into the supply chain. With its ability to integrate real-time monitoring and control systems, SCADA enables accurate monitoring of the production, transportation, and distribution of goods from the starting point to the endpoint in the supply chain. The information obtained from SCADA allows stakeholders to track production status, identify weak points in the process, and respond quickly to changes that occur. Thus, SCADA technology not only provides clearer information on supply chain activities, but also enables improvements in planning, accountability, and overall efficiency in managing the supply chain holistically. A recent study discusses related integration of SCADA in inventory tracking and supply chain control systems through the use of SCADA panels and Industrial Internet of Things (IIoT) websites provides crucial data visualization (Raffik, Rakesh, Venkatesh & Samvasan, 2021). The use of photoelectric proximity sensors in the sorting system enables identification and separation of objects based on their size. SCADA is responsible for controlling the sorting operations while displaying information about the available storage space in the inventory. This integrated IIoT intelligent system significantly reduces downtime in the industry.

3. Proposed Method

The proposed method in architecture framework for supply chain management systems integrated with SCADA uses TOGAF method. It conducted the research through several stages as shown in Figure 1.

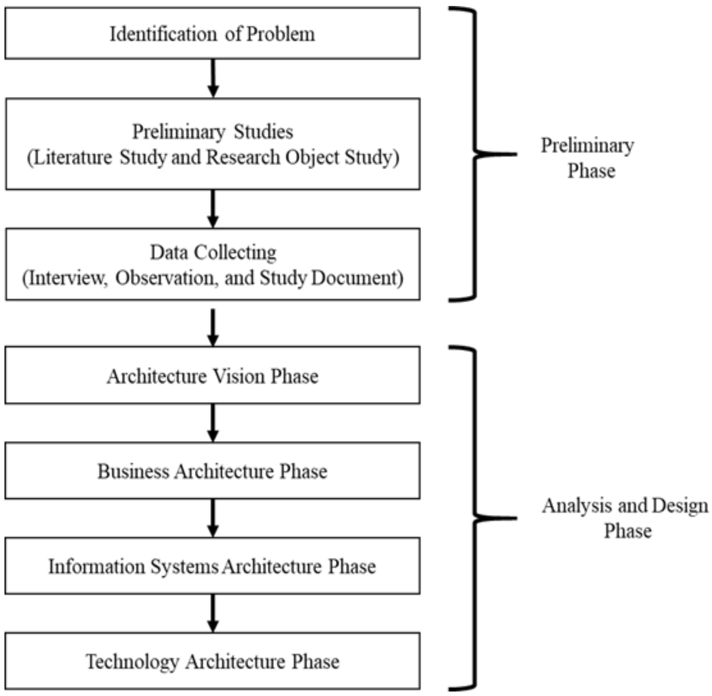


Fig. 1: Proposed Method.

In the figure 1, shows that have several phases in research methodology, here are detailed activities:

- Problem identification
  Define problems or opportunities that require SCADA-SCM integration. The approach is to gather input from stakeholders to understand the concerns, challenges, and desired outcomes related to SCADA and SCM operations. Identify specific areas where integration can address existing issues or improve processes.
- Preliminary studies

Define the scope, objectives, and boundaries of the architecture project. approach is to define the objectives and boundaries of the integration effort. Define the stakeholders involved and their roles. Describe the resources required and constraints that may impact the integration process.

- Data collecting
  The methods used are interviews, observations, and document studies. The approach taken was to conduct interviews with key stakeholders, including operators, technicians, managers, expert, and IT personnel involved in SCADA and SCM. Gather insights on their experiences, challenges, and expectations regarding integration. Observe existing workflows and processes to identify bottlenecks or areas for improvement. Analyze existing documents, reports, system manuals, and protocols related to SCADA and SCM to understand functions, limitations, and potential integration points.
- Architecture vision phase
  Develop a high-level view of an integrated SCADA-SCM system aligned with business objectives. The approach was to further refine the gathered requirements and stakeholder input to create a comprehensive vision. Define key success factors and constraints. Identify critical functions required for successful integration. Develop a vision document detailing the purpose, scope, and benefits of the integration.
- Business architecture phase
  Align business needs with architecture and define how SCADA-SCM integration impacts the organization. The approach is to analyze business processes related to supply chain management and SCADA systems. Identify opportunities for integration that align with business objectives.
- Information systems architecture phase
  Design an information architecture that supports SCADA-SCM integration. The approach taken is to analyze the data structure, matrix relationship between business functions and entity data, information system requirements, candidate applications, and architecture applications.
- Technology architecture phase
  Determine the technology infrastructure required to support an integrated SCADA-SCM system. The approach is to assess the existing technology landscape, including hardware, software, and network infrastructure. Evaluate the compatibility and integration capabilities of various technologies.

4. Result and Discussions

4.1. Preliminary

The preliminary phase is a preparatory and preliminary stage to define the framework and principles aimed at confirming the commitment of stakeholders, determining the framework, and detailed methodology that will be used in the development of enterprise architecture.

Based on the data collected, it was found that there are major challenges related to optimal coordination and visibility in supply chain management. There were gaps in the integration of real-time data from the factory floor to the supply chain management system, which hampered the accuracy of decision-making. This led to a lack of accurate predictions regarding product demand, causing problems in inventory management and production efficiency. In addition, there is a misalignment in the real-time monitoring of the production process and coordination with stock requirements in the warehouse, which has the potential to disrupt overall efficiency in the supply chain, leading to delays in the production process. Based on the identification results, it is clear that the integration between SCADA and SCM has great potential to improve visibility, coordination, and overall operational efficiency in the manufacturing industry.

The scope of the architecture is related to information systems that exist in the manufacturing industry regarding supply chain management. these activities will be explained at the stage of architecture vision. Key stakeholders that are involved in architecture planning of information systems include executive management, production departments, warehouses, information technology (IT) teams purchasing, accounting, and marketing and sales. Each stakeholder has unique roles and interests in supply chain operations, and an in-depth understanding of their perspectives will help in formulating an architecture that meets their needs.

Framework that is used in architecture planning of information system supply chain with SCADA based in four phases of TOGAF ADM method. phases used in this research are vision architecture, business architecture, information system architecture, and technology architecture. this research aims to make a blueprint for supply chain management information system architecture. Tools that are used are BPMN, value chain, and UML diagram.

The architectural principles in the SCADA-based Supply Chain Management (SCM) Architecture related to business, data, application, and technology aspects can be seen in Table 1.

Table 1: Architecture principle.

Architecture	**Principle**
Business	• Value-oriented • Development of appropriate • Supply Chain Optimization
Data	• Data Quality • Data Integration • Data Security
Application	• Real time monitoring • Intuitive User Interface • Functionality-Centric
Technology	• Technology Scalability • Integration technology • Automatic data capture

4.2. Architecture Vision

Architecture vision Identifying main and supporting activities in an industry company can be described using Michael E. Porter's value chain which is shown in Figure 2.

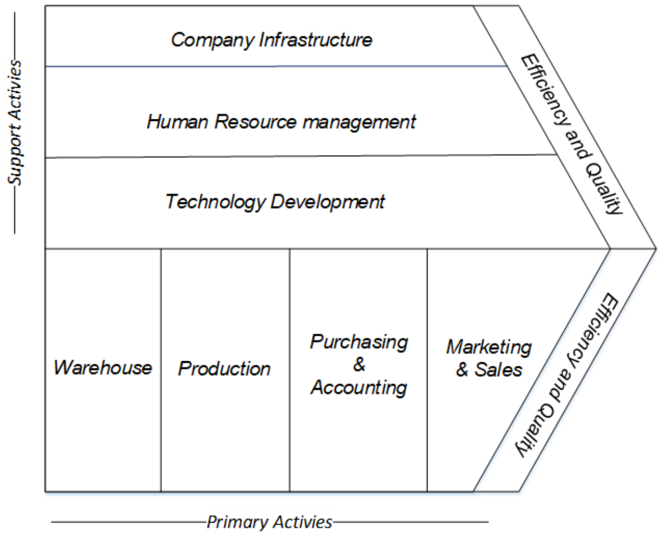


Fig. 2: Value chain main activities of industry companies.

Results of identifying the company's vision resulted in an information system architecture vision that includes:

- IT-based Supply Chain Management information system with SCADA integration to control and monitor company's Supply Chain that supports company's vision.
- Integrated information systems in Supply Chain Management process to improve customer service.

4.3. Business Architecture

Business architecture design is implemented with a focus on processes related to Supply Chain Management, such as material procurement, production, logistics, and customer distribution in companies. Business Process Mapping Notation (BPMN) is used to analyze and describe a company's business processes. main activities include production, logistics, marketing, and financial management, with relationships between company, customers, and suppliers as material suppliers as shown in Figure 3.

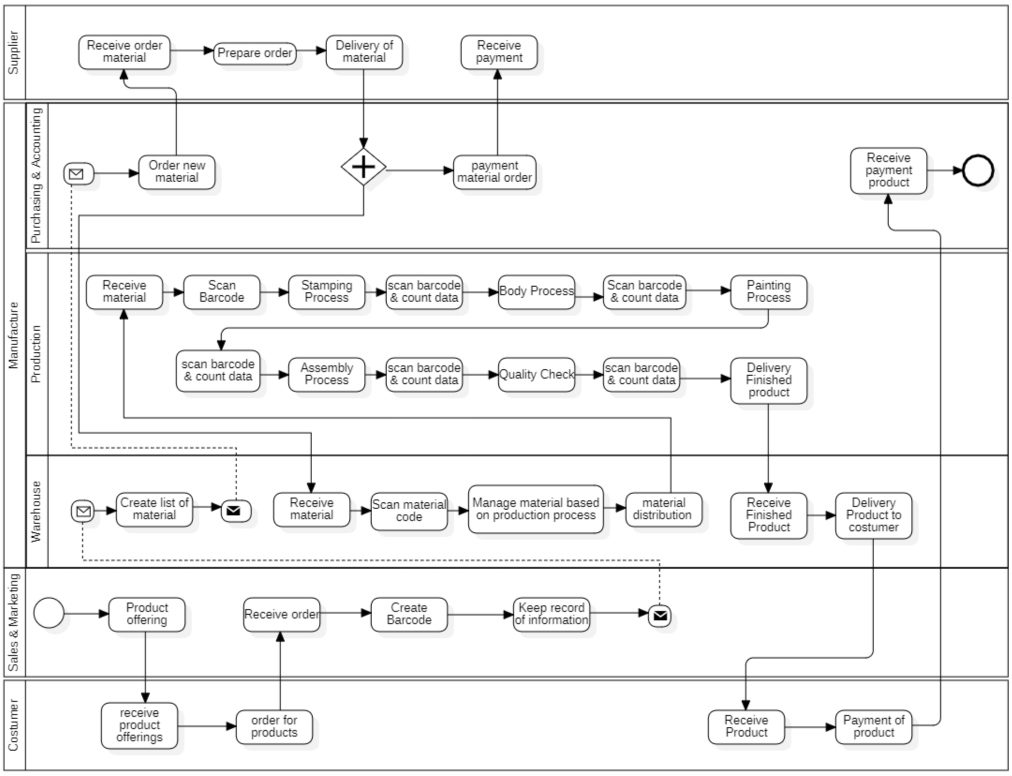


Fig. 3: Value chain main activities of industry companies.

Figure 3 describes the initial stage of the business process when the sales and marketing division offers products to customers. After receiving a product order from a customer, Sales department creates a customer order and creates a barcode that contains information related to the product ordered. The information is then sent to the warehouse to compile a list of required materials and forwarded to the purchasing department to order materials from suppliers. The finance department will make payment based on the material order to the supplier. After the materials are delivered to the warehouse, materials will be managed according to the production process and then distributed to the production department. In production process, such as the stamping process, will scan the barcode and verify the information based on the customer order. After the stamping process is completed, the next process is body installation, painting, assembly, and quality check. At each stage of production, the product will be barcoded and the warehouse will prepare it based on the data scanned at each step in the production process. After all stages of production are completed, the products will be sent back to the warehouse and then distributed to customers. The customer will make the payment process after receiving the product.

Gap analysis of the industrial business architecture is an important step in identifying the differences between the current condition and the proposed solution for supply chain management. Gap Analysis is shown in Table 2.

Table 2: Gap analysis on business architecture of industry companies.

Current IS SCM	Analysis / proposed solution
No integration of IS in each part of the main business process activities.	Integrating all parts of the main activity
No access to monitoring and control of the supply chain in the production process	Integrate with SCADA to control and monitor the supply chain in the production process and warehouse.
Database of the SCM information system is not yet integrated, resulting in data duplication.	Upgrade data infrastructure and design an integrated database

4.4. Information System Architecture

Planning architecture of Supply Chain Management information system, focus on developing data architecture and application architecture. Data architecture identifies data components required to generate information according to needs of business functional areas. Application architecture analyzes needs of application architecture and data relationships within it.

4.4.1. Data Architecture

Identifying data that supports key business functions involves defining data entities associated with company's value chain. In addition, it is also necessary to define relationships between data entities in context of business functions. Data entities in business functions in company which shown in Table 3.

Table 3: Data entities on business functions of industry companies.

No	Business Functions	Data Entity
1	Sales and Marketing Business Functions	• Customer Order • Shipment information
2	Purchasing and accounting business functions	• Purchase Request • Supplier Material Payment • Customer Product Payment
3	Warehouse Business Functions	• Supplier Receipts & Shipment information • Inventory & stock movement
4	Production Business Function	• Production Process information • Production Material Requirement • Production Schedule

To determine entity relationships between business functions, a matrix is used that identifies entities by business functions that are created, referenced, and updated. matrix of relationships between entities in each business function which is shown in Table 4.

Table 4: Relationship matrix between business functions and data entities.

Data Entity	**Business Function**			
	Sales and Marketing	Purchasing and accounting	Warehouse	Production
Customer Order	CRU		R	R
Shipment information	CRU	R	R	R
Purchase Request		CRU	R	
Supplier Material Payment		CRU		
Customer Product Payment	R	CRU		
Supplier Receipts and shipment information		R	CRU	
Inventory & stock movement		R	CRU	R
Production Process information	R		R	CRU
Production Material Requirement			CRU	R
Production Schedule	R		R	CRU

In data architecture, relationships between entities can be identified through entity relationship diagrams. Each entity has a relationship with other entities in form of a class diagram consisting of entities, attributes, and relationships between entities. Relationships between entities in business processes can be modeled through class diagrams.

4.4.2. Application Architecture

The application architecture is designed to process data that supports business functions and enables SCM integration with other business functions. In addition, SCADA integration was considered to integrate real-time data monitoring with SCM processes within the enterprise system as follows:

4.4.2.1. Determining SCM System Integration with SCADA Requirements.

Information system requirements related to the integration between SCM and SCADA have several aspects of important requirements in application development. This integration requires important requirements that must be considered so that the application can run effectively. The following are details about the needs of the SCM information system with SCADA integration that need to be considered in developing the application illustrated in Table 5.

Table 5: Determining SCM System Integration with SCADA Requirements.

Requirement	**Detail**
Real-time data	SCADA integration ensures real-time data flow from the production process to support inventory management and planning.
Smooth system interaction	The need for smooth integration between SCM and SCADA for efficient data exchange.
Integration of Production Information	Integration of information from SCADA into the SCM system for better information on production conditions.
Accuracy and Responsiveness	A responsive SCM system that manages data from SCADA to improve production and supply chain planning.
Alignment with Lifecycle	SCADA integration planning in the SCM application lifecycle for system maintenance and adaptation as needed.

Through the implementation of this requirement, integration between SCM and SCADA can strengthen overall business applications and processes, ensuring smoother operations and responsiveness toward changes. This effort also focuses on preventing material delivery delays, which are crucial in ensuring the smoothness of the supply chain and the sustainability of the production process. With real-time information from integrated SCADA, applications can anticipate and address potential delays, ensuring efficient and timely production flow.

4.4.2.2. Determining Application Candidates

Determining all lists of applications that will be used by company is carried out. following information systems and application candidates are needed shown in Table 6.

Table 6: List of candidate applications in SCM information system.

Information System	Application Name	Application Code	SCADA Integration
Sales and Marketing Information System	Customer Order Management	AP 1.1	-
	Shipment Tracking System	AP 1.2	-
Purchasing and accounting information systems	Purchase Request System	AP 2.1	-
	Supplier Payment Management	AP 2.2	-
	Customer Payment System	AP 2.3	-
Warehouse Information System	Supplier Receipts & Shipment Tracking	AP 3.1	Yes
	Inventory Management System	AP 3.2	Yes
	Stock Movement Tracking System	AP 3.3	Yes
Production Information System	Production Process Monitoring System	AP 4.1	Yes
	Production Material Requirement Planning System	AP 4.2	Yes
	Production Scheduling System	AP 4.3	Yes

Table of candidate applications in SCM information systems shows applications that support each stage in the supply chain. SCADA integration is seen in most Warehouse and Production Information Systems applications, enabling real-time monitoring of warehouse and production processes. This improves asset and process management, ensuring operational efficiency as well as better decisions in supply chain management.

4.4.2.3. Determine Application Architecture

Application architecture is determined which describes relationship between applications and other applications and SCADA integration in company's business functions. This Diagram is related to application of Supply Chain Management information system. Application architecture is shown in Figure 4.

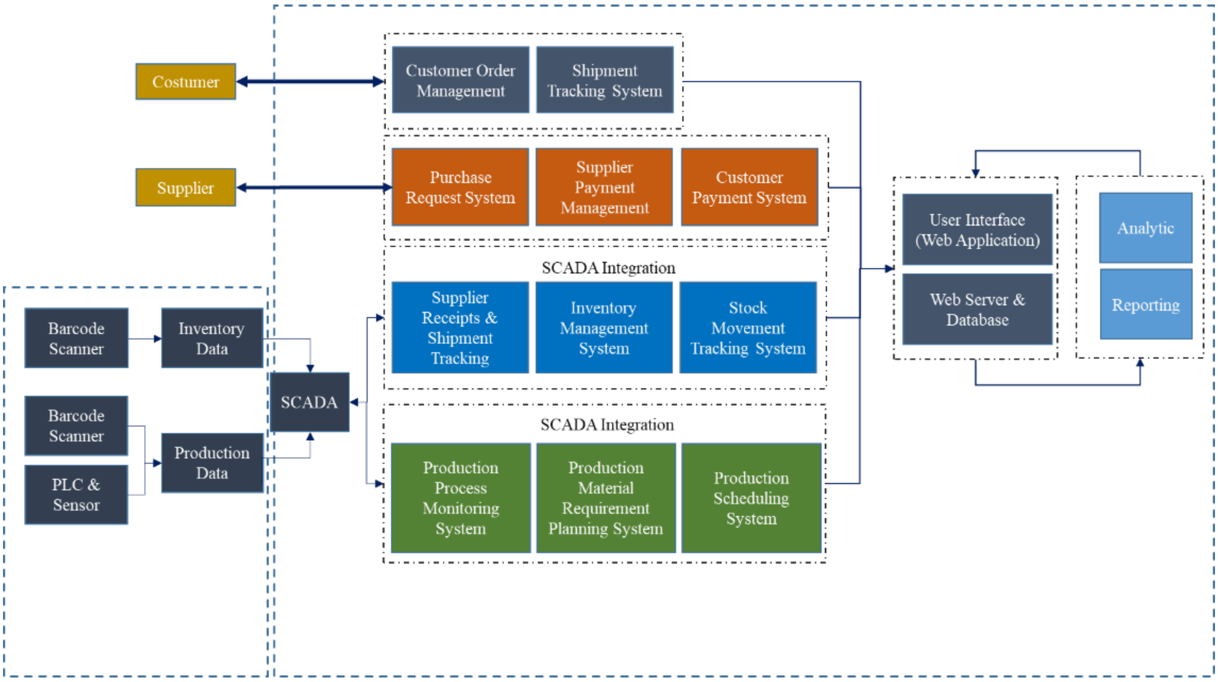


Fig. 4: application architecture of SCM integration with SCADA

Figure 3, describes the integration of SCM applications with SCADA to enable control of production and operational processes in the supply chain. Information related to machine control, production process monitoring, and sensor data can be integrated with SCM applications. This provides greater visibility into machine performance, real-time production status, and changing conditions on the production floor. SCADA integration can support faster and more accurate decision-making in managing production, ensuring operational efficiency, and responding more responsively to changes in the company's supply chain.

4.5. Technology Architecture

Technology architecture of Supply Chain Management information system is designed to produce a reliable information system. In this stage, technology alternatives required to determine appropriate use of technology are considered.

4.5.1. Principle of Technology Architecture

Basic principles of data-sharing technology are used to determine platform and direction of technology provision that supports business processes in company. identification of this principle that matches current architecture, including integration of production data processing with SCADA. Technology principles which show in Table 7.

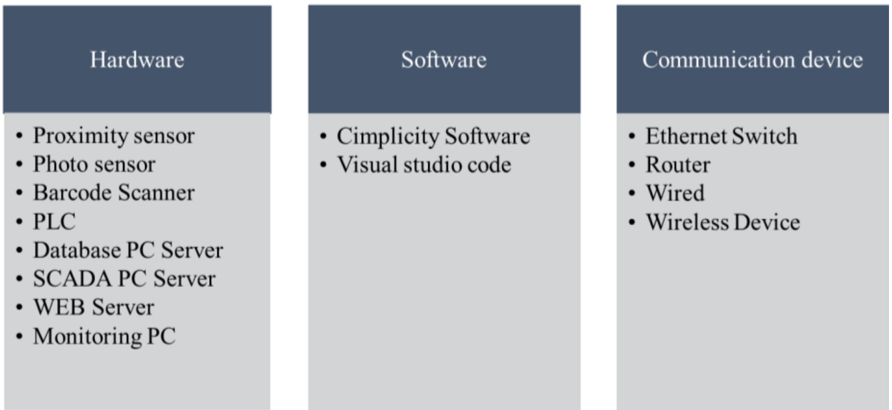
Table 7: Principles of technology architecture.

Principle	Detail
SCM-SCADA System Integration	SCM-SCADA System Integration Integrate data from various points in the supply chain with SCADA supervisory systems.
Operational Security	Implement strong security on SCADA systems that control physical processes in SCM.
Real-Time Availability	Ensure data and information are available in real time for quick decision-making.
Scalability for Supply Chain	Having an infrastructure that can be expanded as the SCM grows or changes.

SCM-SCADA Data Management	Management of data from various sources in the supply chain for analysis and decisions.

Table 7 shows the technology architecture principles used in SCM information systems with SCADA integration. technology architecture must fulfill principles that facilitate users and provide a high level of security. Technology Architecture component that supports SCADA integration is shown in Figure 5.

Fig. 5: Technology architecture component of SCM with Integration SCADA



4.5.2. SCM System Technology Modeling with SCADA Integration

Modeling software and database technology are needed to determine technology architecture used. Server technology architecture in this SCM information system needs to be supported with good technology. following SCM information system which is shown in Figure 6.

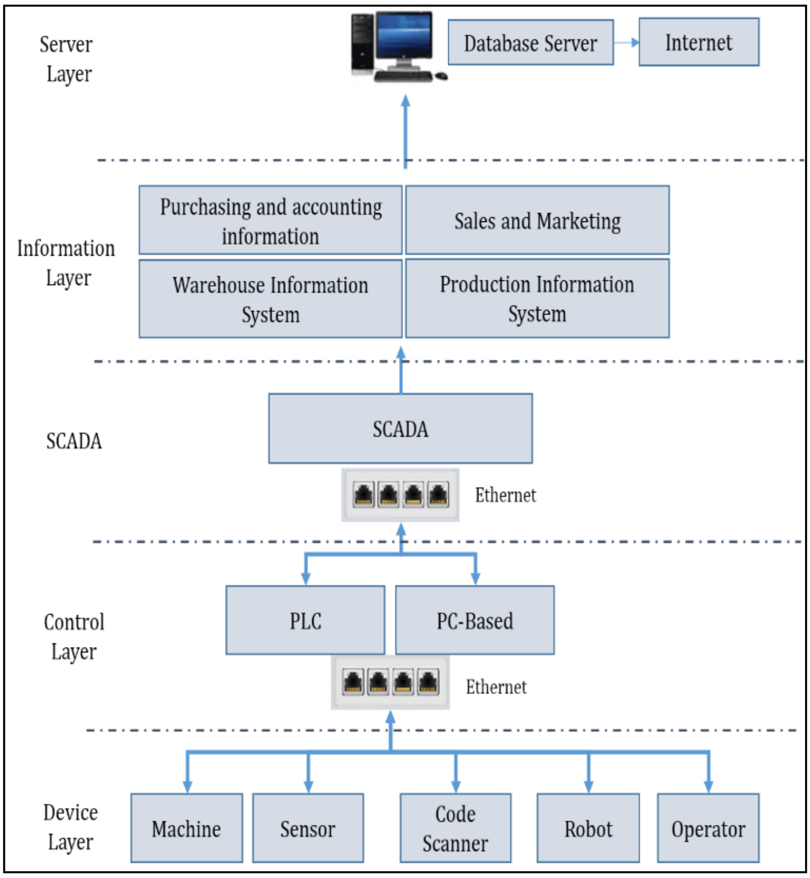


Fig. 6: Information system architecture SCM integration with SCADA

Figure. 6 shows that SCM information system is integrated with SCADA in production area and warehouse. In SCM information system architecture, applications in each section are connected using wireless or Ethernet and can connect to the server. In the production area, data is inputted from production process that uses data from machines used. This includes material usage, production process, and final production output. SCADA can be controlled and monitored by production department, including production quantities, material usage, and product quality.

Integration of SCADA technology with SCM information systems in product production control process. SCADA consists of PC servers used to monitor and control production process. In material processing process, material processing machine sends signals to material handling main control panel and sends status and data regarding material processing process. Material usage is recorded by machine, while type of material is recorded using a barcode scanner. Data regarding type of material and amount of material used is sent to PLC in main control panel and then sent to server PC via Ethernet.

Machines and robots send data on product types and quantities to PLC. Data is used to update machine conditions and product information to be processed. Production results are recorded using a barcode scanner and sent to PLC via main control panel, then sent to PC Server via Ethernet. Products that have been processed and have passed quality inspection are scanned using barcodes to retrieve product type data and product information ready to be sent to supplier. This data is sent to PLC through main control panel and then sent to PC Server via Ethernet.

Data from SCADA is integrated with SCM information system to monitor and control product production process and inventory data. This data is important for analyzing problems that occur in SCM and is used in managing product delivery schedules to customers and material procurement.

5. Conclusion and Future Work

This research theoretically proposes and models an architectural fusion of SCADA capabilities within supply chain information systems to remedy production delays and associated costs. An explanation of the various databases, software, and hardware underpinning this design has been presented, but an empirical assessment on quantitative performance factors would be valuable future work. Additionally, examining case evidence from industries that have initiated integrating industrial control technologies could reveal practical challenges interdisciplinary tools pose. With maturation of automation and Industry 4.0 imperatives, blending operational data with managerial information systems is likely inevitable. Beyond manufacturing, expanding this connected, responsive SCM blueprint across e-commerce, healthcare, and governmental verticals could accelerate realizing digital transformation goals.

For future work, it can be further research to empirically assess quantitative performance factors associated with the implementation of SCADA integration in supply chain information systems. This could include analysis related to operational efficiency, cost reduction, and measurable productivity improvement.

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