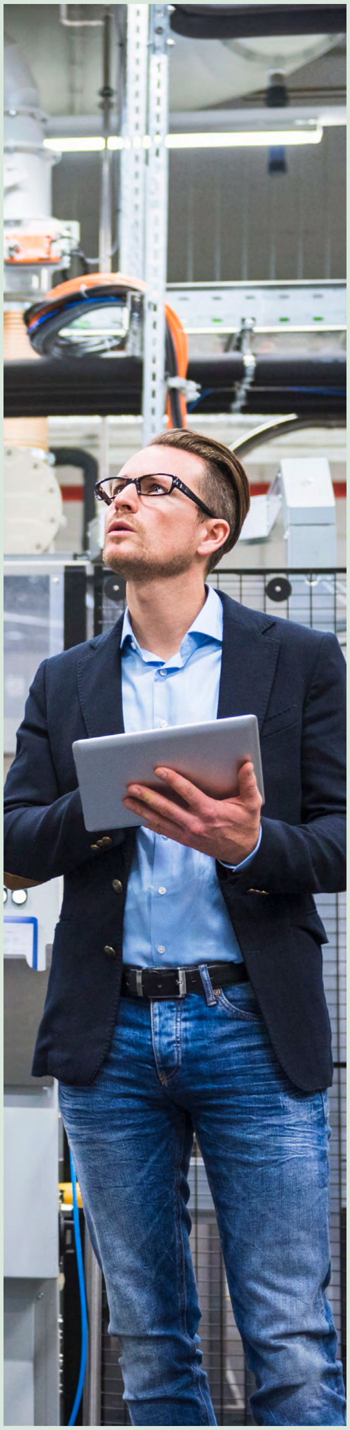
WHITE PAPER



SMART APPROACHES FOR MIGRATING LEGACY DEVICES FOR DIGITAL MANUFACTURING

Abstract

With the Industry 4.0 revolution, the manufacturing industry is changing tremendously by opting for digital transformation. It is a big leap forward after industrial automation, utilizing present-day legacy systems and adopting newer technologies it is a more concreted effort to digitalize holistically and not in an ad hoc manner. Legacy systems dominate many manufacturing companies. So, almost 50% of installed systems need reengineering with digital technologies to increase competitiveness and agility in manufacturing. Many of these legacy systems have already attained or are nearing end-of-life and cannot drive the next level of growth for digital manufacturing. Various studies conducted by industrial innovation leaders about legacy systems and digitalization studies suggest different solutions to transform them before retiring or phasing them out. This paper discusses the pain areas and various strategic solutions to migrate legacy systems to the modern digital manufacturing ecosystem. It provides insights into a digitalization roadmap with highlights on practical solutions. It also underlines some of the best practices to implement and realize benefits.

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1. Introduction

Industry 4.0 is revolutionizing manufacturing by enhancing production experience, optimizing the production process, and elevating overall plant efficiency. Big manufacturing organizations with huge capital investments are using Industry 4.0 and integrating production data collected from the plants with cloud-based technologies like Artificial Intelligence (AI), Machine Learning (ML), Blockchain and Big data analysis. These enhancements are built on a robust digital platform backbone to nurture innovation by creating real-time data insights and analytical intelligence.

Digitalization of manufacturing plants utilizes the Smart Factory initiative, where ubiquitous sensing across different manufacturing processes results in huge volumes of vital process and production information. Digital transformation of the manufacturing landscape is essential for its integration with cloud based modern applications. Moreover, it helps the enterprise to deliver added value to its customers by providing goods and services of expectable quality and quantity at optimum costs and a predictable timeline. In general, the level of digitalization determines the future growth prospects of any manufacturing enterprise.

However, the major hurdle to digital transformation is the presence of legacy systems in manufacturing plants. This paper discusses different solution strategies to digitally transform legacy systems and recommends critical factors to be assessed along with best practices.

2. Legacy Manufacturing Systems and Challenges

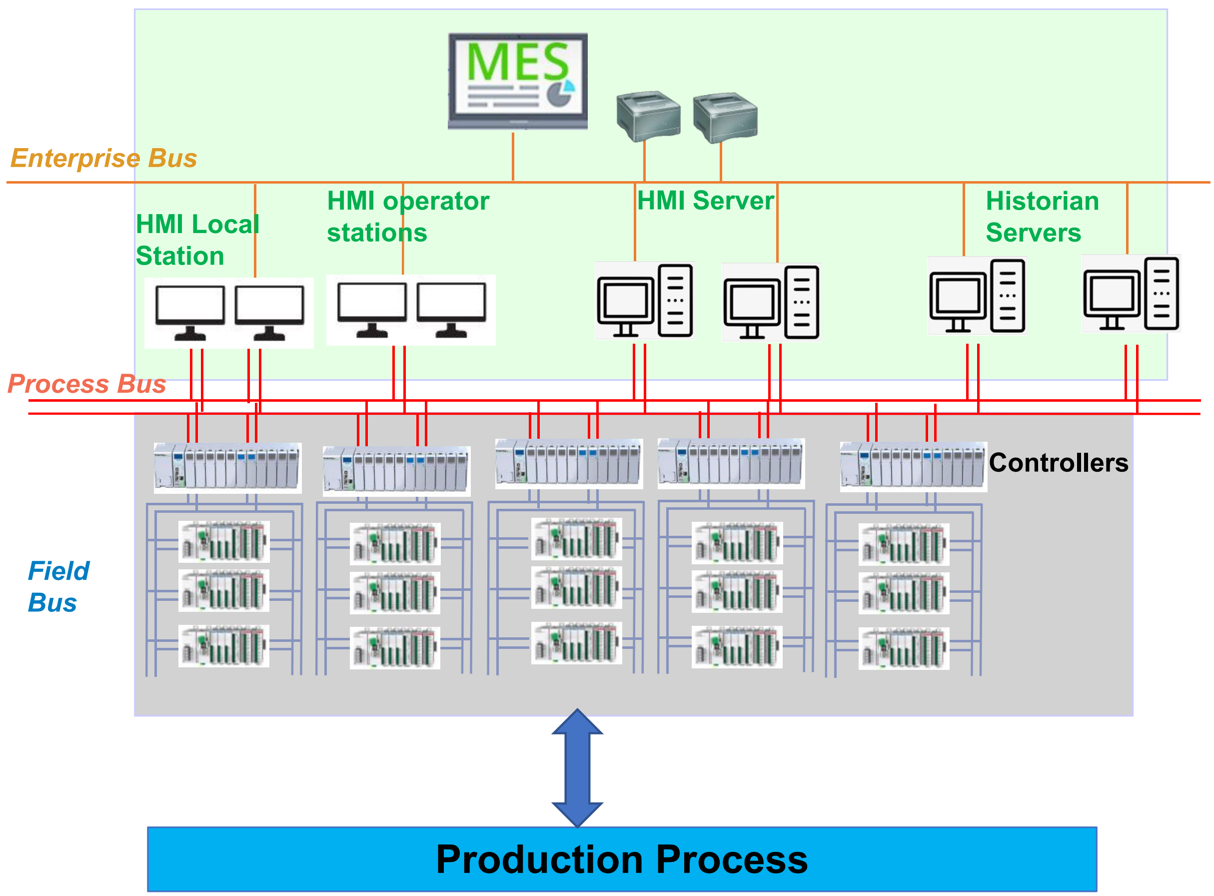

Figure 1 Typical architecture of a manufacturing plant.

Supply chain agility, cybersecurity and Smart Factory technologies are the three top technical demands for the digitalization of manufacturing [1]. Around 58% of manufacturers surveyed were keen to increase their level of digitization by utilizing Smart Factory technologies [2]. However, most manufacturing plants commissioned several decades back possess legacy control systems with limited data exchange capability and network connectivity. In addition, enterprise mergers have created a heterogenous landscape of legacy systems, further complicating the situation. Despite using outdated technologies, legacy systems are crucial as they currently run manufacturing operations.

Furthermore, users are familiar with the legacy systems and find them reliable hence resisting change. But they are often not integrated with other business solutions such as smart asset monitoring or closed loop analytical services. Moreover, their inherent risks can result in substantial losses (detailed in section 3).

Figure 1 shows the logical architecture of a typical manufacturing plant with legacy systems. In such a scenario, the data collected from the production process is used for plant automation but not effectively applied to achieve manufacturing intelligence for optimum operations.

According to a recent industry survey, legacy systems comprise approximately 31% of an organization's technology portfolio, while conventional systems constitute about 36% [2]. Both legacy and conventional systems by design are unsuitable for full-scale digital transformation.

2.1. Key reasons to retain legacy systems

Operational technology systems hardly change fast as many factors need careful consideration.

- Requires huge capital investment – Most manufacturing enterprises lack the budget to migrate, re-platform or replace legacy systems. As a result, digital transformation with huge capital expenditure pushes legacy system migration plans to the backseat.
- Presence of custom build intellectual properties – Legacy customized technical solutions have been used for many years in manufacturing plants. As a result, management is typically reluctant to replace the intellectual properties developed around legacy systems that perform business operations reliably, sometimes to even relinquishing the benefits of technology modernization.
- Lack of off-the-shelf solution - No ready-to-use legacy migration solution is available. It requires significant expertise, planning and effort from a manufacturing enterprise to transform legacy systems.
- Fear of business uncertainty – The management anticipates risks that may adversely affect business operations, disrupting the as-is' normal' situation due to technical defects that can creep in during modernization.
- Operational risk due to commissioning delay – Legacy system modernization should be time-bound. Therefore, any delay in commissioning the upgraded plant can backfire on production planning and jeopardize manufacturing commitments.

3. Challenges with legacy manufacturing systems

Studies indicate that 70% of digital transformation projects in manufacturing fail[3][4]. The major bottleneck is the complexity of upgrading legacy technologies. The idea of rebuilding the whole plant by swapping legacy systems with modern systems is not viable due to the high risk of failure, huge capital requirement and large production downtime. But retaining legacy systems leads to potential pain areas (Table 1). On the other hand, research suggests that migration can improve productivity by up to 30% and reduce time to market by up to 40% [5][6].

Business Need	Business Limitations	Technology Limitations	Description
Capture more data from processes for better understanding and optimization	No right data, fear of business uncertainty	Device layer issues	• Non-modular and monolithic architecture using outdated technologies. • Huge reengineering effort is needed to capture data. • Most legacy systems are out of warranty and lack vendor support.
		Unpredictable failures	• Too many crashes and require frequent maintenance. • Large downtime and cost for maintenance due to unexcepted breakdowns.
		Lack of scalability	• Rigid architecture makes vertical and horizontal scalability difficult with business growth.
Integrated processes, near real-time contextual information across the value chain and optimization	No off-the-shelf solution, delays in commissioning	Lack of information	• Legacy systems are black box devices with captured data locked inside. • Captured data used is seldom used for creating data intelligence.
		Connectivity Issues	• Uses proprietary communication protocols which can connect to a small subset of systems. • Communication lacks optimum data transfer and is often resource intensive. • Connectivity is not suitable for large volume data transfer.
		Non-standard APIs and database	• Modifications are required to extract data from legacy devices with no standard API interfaces. • Huge effort is required to reverse engineering data restructuring and to remapping to tap propriety data from old databases.
Collaboration with internal and external stakeholders	Security issues	Cyber security risks	• Usage of obsolete technologies, which are prone to cyber-attacks.
		Compliance with regulatory requirements	• Difficulty in meeting ever tightening regulatory requirements for safety and good manufacturing practices.
Root cause analysis, quick decision making across the manufacturing value network	Operational risks and lost production	Performance issues	• Low productivity due to higher configuration, lead and cycle times. • High operational and maintenance costs.
		Data processing limitations, lack of context	• No support for high volume real-time data processing.
	Difficult to Operate	Archaic technologies	• Outdated user interfaces and technologies make legacy systems highly complex and difficult to operate. • Operators require specialized skills to operate legacy devices. Only experts can detect and solve technical and operational issues.
		Lack of mobility	• Tied to a location inside the plant with permanent cabling and cabinets. • Operators control these systems from specific workstations

Table: 3

4. Harnessing IIoT integration to transform digital manufacturing

To address the challenges identified in section 3, organizations need a well-focused effort that includes evaluating and adopting suitable technologies, preparing the workforce, implementing the appropriate IT/OT infrastructure and adjusting business processes.

Section 4.1 discusses strategic solutions to address these challenges and transform legacy systems by adopting efficient, cost-effective, quick approaches.

4.1. Legacy to digital manufacturing strategy

4.1.1. Evaluate manufacturing landscape

It is vital to understand the current maturity level of the manufacturing landscape to define its digital transformation strategy. A global study conducted by Infosys and the Institute of Industrial Management (FIR) defines six levels of maturity Index [7], which can be utilized for the assessment:

- Two technical levels to indicate the readiness for the digital journey
  - Computerization
  - Connectivity
- Four sequential functional levels characterizing systems for
  - Visibility (what happens?)
  - Transparency (Why does it happen?)
  - Predictability (What will happen next?)
  - Adaptability (How can autonomous reactions occur?)

The maturity index can be assessed in four holistic dimensions –

- **Information systems** - all processes for collection, organization, storage and communication
- **Resources** - operational, physical as well as intangible resources
- **Organizational structure** - any corporate structure, alignments and regulations
- **Culture** – to create a new workplace and industry environment

Based on the current maturity index and feasibility studies, legacy systems are categorized as high, moderate and low critical for digital transformation.

4.1.2. Digital migration feasibility

A feasibility study and a pilot implementation help decide on the organization's best migration strategy.

Legacy systems that pass the feasibility test can be digitally transformed using three broad strategies:

- Wrap and reuse
- Rip and replace or
- Hybrid approach

4.2. Wrap and reuse

The wrap and reuse solution retains legacy systems as much as possible by implementing a middleware that bridges existing legacy systems with modern digital systems. Figure 2 shows a middleware implementation using a wrapper, web API layer and web services. The wrapper standardizes the communication layer and hides the legacy systems beneath it. The web API layer and web services make the interface accessible from modern digital systems. For example, the OPC UA server is a widely used solution for wrapping legacy systems with proprietary protocols support and exposes service-based interfaces to modern digital systems. In some cases, legacy systems require modifications, re-platforming or even implementation of a few software modules. Wrap and reuse solutions can be classified into two sub-categories.

4.2.1. Legacy system migration using a gateway or middleware -

The solution depends on building middleware or a gateway. Middleware taps data from legacy systems and sends it to applications in cloud based digital environments. It wraps and provides a service-oriented interface to modern digital systems while still using backend legacy systems. For example, a power generation plant with legacy automation controllers with serial Modbus can be integrated with industrial cloud applications using a serial Modbus to MQTT converter (middleware). The middleware also protects the legacy system from cyberattacks. This implementation can be executed parallel to the existing plant setup without vendor support.

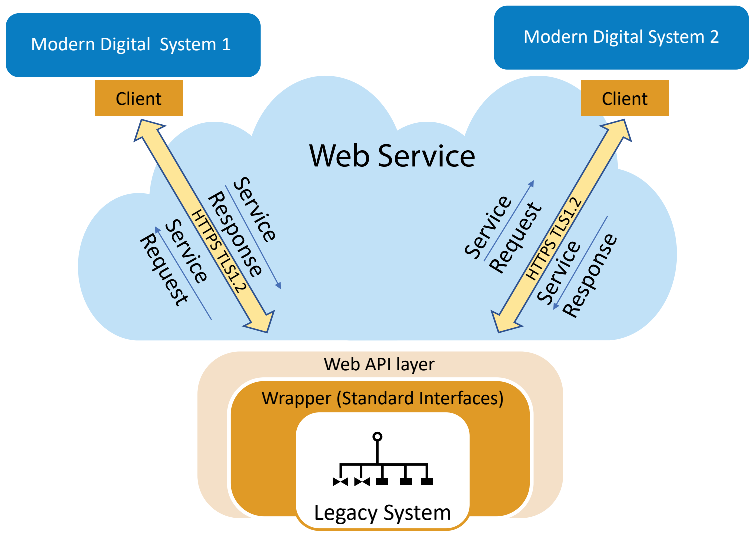

Figure 3 Wrap and reuse with middleware

4.2.2. Upgrade the legacy system

Some legacy systems are closed systems and cannot interface with middleware. Such legacy systems require modification, which includes peripheral module replacement to software module implementation or modification, typically with vendor support. The most common solutions to transform legacy systems are -

- Add new I/O peripheries to improve connectivity to modern digital systems
- Install modules or protocol convertors from the vendor to improve connectivity
- Off-the-shelf or custom-built solutions - for example, Matrikon provides various COTS solutions for legacy protocol transformation like Matrikon Data Broker [8]
- Re-platform the system to a powerful hardware or operating environment
- Code refactoring, modification, and upgrade of a few software modules
- Implementation of new software modules to the system.

The wrap and reuse approach hides the legacy system issues in the backend rather than solving them permanently. However, after a few years, these deficiencies may magnify and reach a state of end-of-service, making replacement the only option. Hence there should be a reasonable retirement plan to replace legacy systems with a modern digital system in the long run.

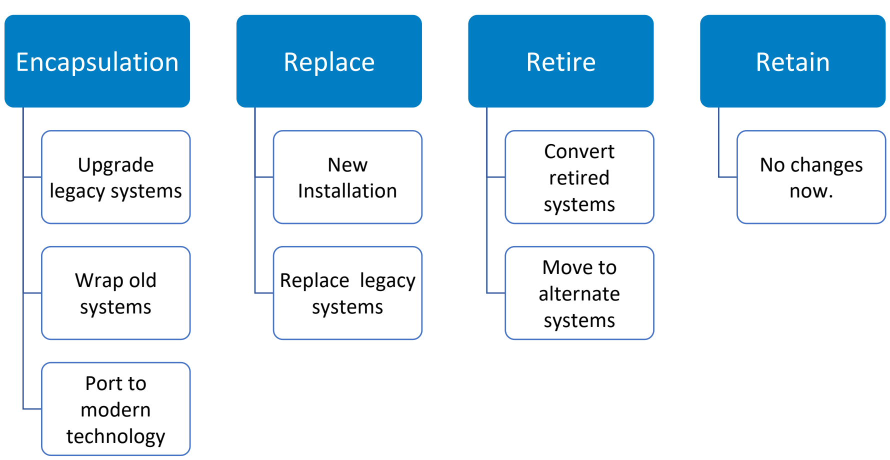

Figure 4 Solution strategies for Legacy system migration

4.3. Rip and replace

Industrial control systems have been built to run for decades. Many mechanical elements are selected so they can be rebuilt or replaced with little difficulty. However, the automation system hardware and software used for such equipment can become difficult to maintain due to factors mentioned in section 3, resulting in increased unplanned downtime.

In some cases, automation systems can become unsupportable. Users are then left with an option to either rip and replace or upgrade and integrate with a new automation system. Both modernization options can be difficult and time-consuming, not to mention expensive. In general, the rip and replace the strategy of legacy control systems will include moving the legacy control systems to the latest current hardware by removing the control system — including I/O—and completely reengineering the control software. This approach needs careful planning and execution for a successful migration.

4.4. Hybrid solution

The hybrid approach combines the benefit of both the solutions discussed above. It upgrades the legacy systems and captures additional data points from the field for beneficial use cases like remote condition monitoring, condition monitoring and predictive maintenance while using cloud technologies. Note that the wrap and reuse solution does not capture additional information from the field. In addition, rip-and-replace solutions can affect manufacturing due to the loss of custom-built intellectual properties introduced with legacy systems. For example, a pharma plant desiring to migrate a legacy system without affecting the intellectual property developed requires a hybrid solution.

The hybrid approach reuses legacy systems using wrap and reuse and introduces modern controllers to capture additional data points required for new age IIoT applications. New controllers are installed in parallel to legacy systems (Figure 4). Modern controllers use IIoT technologies that are enabled in the collection (to do remote monitoring and diagnostics), connection (to an intelligent system in cloud), ingestion (enhanced data analytics and reporting), and integration of the digitized data. Furthermore, smart sensors that allow signal and data processing to decision-making processes to be implemented on a chip of the sensor itself can be used. In addition, emerging technologies like Low Power Wide Area Networks (LPWAN) and wireless I/O devices offer innovative connectivity solutions.

Once the data is digitally collected, data can be fed into the cloud. The data can be applied with various digital and physical technologies, including analytics, additive manufacturing, robotics and high-performance computing.

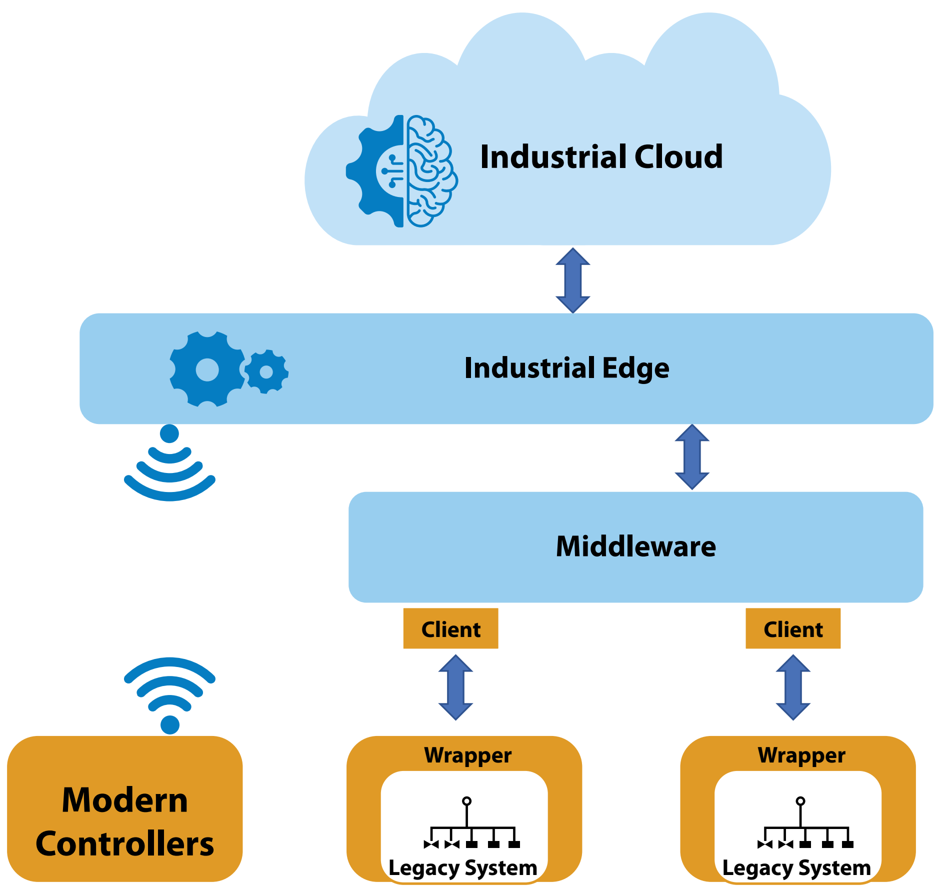

Figure 5 Hybrid solution for legacy system migration

Table 2 summarizes the pros and cons of the three strategies.

Strategy	Pros	Cons
Wrap and reuse	Faster time to market	Integration issues
	Better RoI, cost-effective	May not offer all benefits of the latest technologies
	Scalable and highly customizable	Maintenance issues
	Lower risk involved	Proprietary solutions
	Minimum effect on production commitments.	
Rip and replace	State-of-the-art, future-ready technology	High hardware and installation costs
	Reliable and easy to maintain	Long transition
	Good long-term investment	Will cause longer downtime
	Best in performance and indicators	
	Generic solutions with good vendor support	
Hybrid	Better integration with a modern industrial cloud-based application.	Maintenance issues
	Retains intellectual properties developed with legacy system	Lack of performance due to custom solutions.
	Lower time and capital requirements with maximum benefits.	

Table 2: Comparison of Migration Strategies

4.5. Typical architecture of legacy to a digital modernized system

With IT and OT convergence and virtualization technologies, many engineering and software applications are moving to the cloud. Integrating cloud technologies allows process control systems to perform edge computing and serve as data sources for the IIoT.

Figure 5. presents the typical architecture for modernizing legacy manufacturing systems to cloud-based IoT systems. The emerging technologies AI, ML, augmented reality, analytics, and business intelligence (BI) help analyzes and act appropriately on production and product data. Predictive maintenance of key assets using predictive algorithms optimizes repair and maintenance schedules and improves asset uptime. Horizontal integration and tracking and tracing of products help with better inventory performance and reduce logistics. Two standards, NAMUR Open Architecture (NOA) and Open Process Automation Forum (OPAF), drive open architecture initiatives in industrial automation digital transformation by moving away from proprietary architectures. Open concepts like Modular Type Package (MTP) based on NE 148 of NAMUR define standard machine/module to communicate on a standard package format. These describe how vendor-neutral systems can use state-of-the-art equipment and functions, avoiding the common problem of vendor lock-in. Key concepts of such standards include interoperability, modularity, conformity to standards, compliance with security standards, scalability and portability.

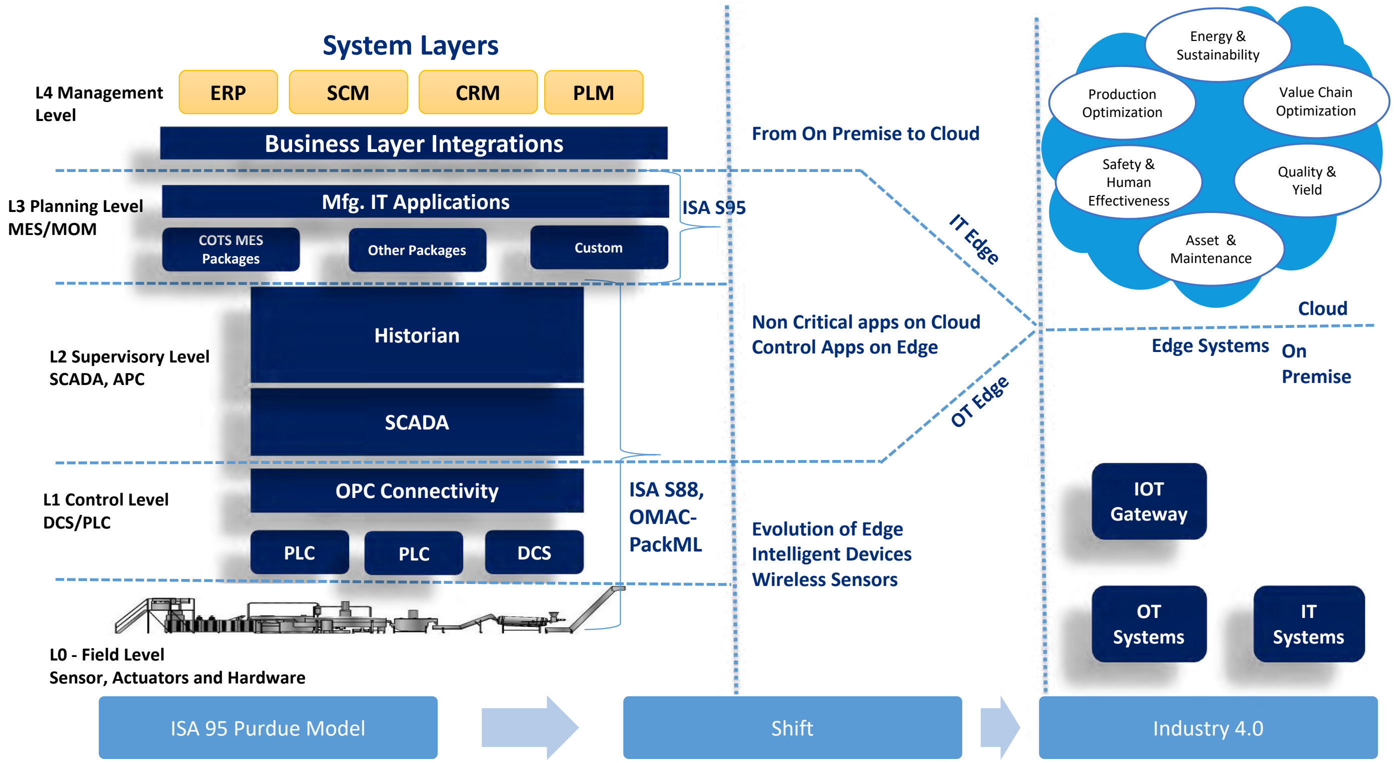

Figure 5: Typical Architecture of Legacy to Digital Modernization

5. Best practices for digital migration

Digitalization of manufacturing systems is an imperative need. The following best practices are recommended for mitigating the challenges when pursuing it.

Business Challenge	Best Practice
No right data, fear of business uncertainty	• Adopt modular, loosely coupled architecture with the latest advanced technologies to build a scalable solution. • Introduce device provisioning and automate the process of authentication. • Monitor the health parameters of devices, predict the failure and address the reason for failure before it gets failed, thereby improving the device's life. • Support Open Platform standards for better interoperability.
No off-the-shelf solution for migration, lack of integrated processes	• Evaluate and cleanse data before legacy system migration to reduce storage. • Remove duplicate and unwanted data from the transmission to cloud or edge layer to reduce network bandwidth. • Support Open standards like OPC UA and IEC between the device layer and to data layer to comply with regulatory requirements. • Use widely accepted open cloud based protocol standards like MQTT and AMQP for cloud communication. • Adopt microservice based architecture to improve the scalability of the system. • Use open-source systems like Apache Spark/Apache Flink/Apache Kafka for data streaming. These streaming databases provide resilient storage that will not lose important messages. Moreover, it can scale horizontally beyond the next or even next-next order of magnitude. • The data storage layer should cover scalability (handle a rapid increase in the number of devices and volume of data they generate), consistency, availability (to achieve high availability (HA) and disaster recovery (DR), big data (to handle a large amount of data) and real-time analytics (to provide downstream reporting based on data analytics. The value of data should not be missed.
Security issues with wider collaboration	• Provision modern IIoT devices and systems with unique identities and credentials and apply authentication and access control mechanisms • Data at rest is vulnerable to manipulation, and its confidentiality, integrity and availability (CIA) must be protected. Data encryption and replication are the most common techniques used to ensure CIA protection for data at rest to mitigate the risks of exposing sensitive information to intruders. • Authentication and authorization mechanisms to limit access to the IoT apps
Operation risks and lost production	• Adopt the best data handling strategies and best practices to improve system performance.
Difficult to operate	• Rich user experience with modern UI technologies with ease of operation. • Provide responsive UI to support multiple devices like mobile, tablet and desktop.

Conclusion

Digital transformation of legacy systems is a top priority for the manufacturing industry. However, selecting the best solution strategy requires thorough analysis and expertise in retrofitting legacy systems. The solution provider must consider various critical factors and evaluate advanced technologies to plan an effective and viable strategy. Finally, the provider must validate the strategy properly with small projects before finalizing the upgrade plan for the manufacturing plant.

Assessment frameworks for evaluation backed with a sound cross-functional team and committed leadership are essential for progress in digitalizing the enterprise. In addition, overcoming cultural challenges is equally important while addressing the challenging technical environment to achieve the desired business outcomes.

This digital transformation yields more secured data, enables data-driven decisions, greater accuracy, control, and visibility in manufacturing and establishes a rich data stream from smart, connected products. In addition, integrating PLM, CAD, ERP and CRM improves plant efficiency and throughput.

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