

The Lenovo logo is displayed in white text on a black rectangular background.

Lenovo Validated Design for Smart Manufacturing with ThinkEdge Solutions

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Version 1.0

Introducing manufacturing solutions for Industrial IoT with Edge architecture

Including real-time production monitoring and business Intelligence

Leveraging AI Quality Inspection on the Lenovo ThinkEdge SE30

Showcasing Digital Twin with Lenovo ThinkEdge SE450

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1 Introduction

This document describes the reference architecture for the Manufacturing Solution (Project name Optimus) developed in partnership with the CERTI Institute (<https://certi.org.br/en/>) in Brazil. Lenovo and CERTI collaborated on the architectural vision and engineering effort to create this comprehensive reference architecture for manufacturing solutions utilizing Lenovo ThinkEdge devices. This paper aims to provide planning, design considerations, and best practices for implementing these solutions.

The architecture detailed in this document has been validated by both Lenovo and CERTI. The intended audience includes IT professionals, technical architects, sales engineers, and consultants. This document is intended to support the planning, design, and implementation of Industry 4.0 manufacturing solutions.

Industry 4.0

Industry 4.0 is driving a transformation in manufacturing sites worldwide by integrating digital technologies that bridge the physical and digital worlds. Key technologies include:

- Autonomous robots and collaborative systems (cobotics)
- Industrial Internet of Things (IIoT)
- Big Data and cloud computing,
- Artificial intelligence (AI),
- Integration and simulation,
- Additive manufacturing and augmented/virtual reality (AR/VR).

These technologies offer numerous direct benefits, improving the performance and reducing wastes. These advancements enhance the quality, flexibility, and adaptability of production lines, ultimately resulting in higher overall gains.

Industrial IoT

The term Industrial IoT (IIoT) originated from the Internet of things, which was initially defined by Ashton [1]. As with its predecessor, IIoT has various definitions in both industry and academia. However, all definitions converge on the idea that the primary focus of IIoT is the collection of data and actuation between physical and cyber systems. This interaction forms the basis of the cyber-physical system (CPS) concept, which is a fundamental element of Industry 4.0, as illustrated in Figure 1.

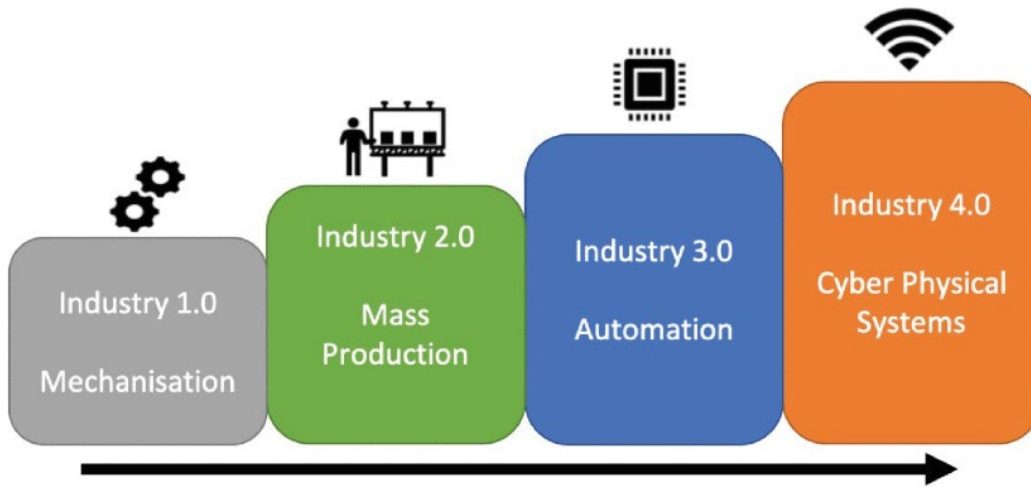


Figure 1 - IIoT and Cyber-physical System

Source: Fuller, A. et. al. 2020 [2]

Digital Twin

One of the most advanced technologies in Industry 4.0 is Digital Twin. This technology integrates virtual and physical models, where real-time data is collected from the physical model and transmitted to the virtual model, while commands are sent from the virtual model to the physical one. This bi-directional feedback loop allows the virtual model to replicate and interact with the physical model dynamically.

The term “Digital Twin” was defined by Dr. Michael Grieves at the University of Michigan around 2001-2002, originally within the context of Product Lifecycle Management (PLM). Dr. Grieves introduced the concept as a virtual representation of what has been manufactured, proposing the idea of comparing the Digital Twin to its engineering design. This comparison helps to better understand discrepancies between what was designed and what was produced, thereby tightening the loop between design and execution [3].

As pointed by Fei Tao, et. al. [4] the digital twin was one of the most promising technologies for enabling the Industry 4.0 with a seamless integration between cyber and physical spaces. Creating a Digital Twin involves integrating flexible and modular manufacturing systems such as ERP (Enterprise Resource Planning), MES (Manufacturing Execution Systems), MOM (Manufacturing Operation Management), PLM (Product Lifecycle Management) among others.

In its advanced state, a Digital Twin can simulate the behaviour of a real physical model - such as a manufacturing plant - under various input and boundary conditions (environment, constraints, etc.), and act on it with artificial intelligence. This enables accurate prediction of the system's operation and allows for autonomous control of the physical model's processes in the event of changes or disturbances in production. Additionally, it supports predictive maintenance by automatically scheduling maintenance activities when necessary.

Edge Computing

Unlike the well-known cloud computing approach where the data storage and processing are centralized in a single location, Edge Computing (EC) brings data processing closer to the data source in decentralized nodes. This approach reduces latency and bandwidth requirements, making it an ideal application in smart cities, retail,

manufacturing applications that require rapid decision-making closer to the sensors.

Edge Computing offer several benefits:

- **Improved control data manipulation:** By keeping data within on-premises infrastructure, organization can have better control over their data.
- **Distributed AI Processing:** Multiple nodes can process AI tasks, enhancing the efficiency and speed of the amount of data sent to the cloud.
- **Cost Reduction:** Edge Computing can reduce costs associated with cloud services by minimizing the amount of data sent to the cloud for processing.
- **Enhanced Privacy:** Data privacy is improved as sensitive information can be processed locally without being transmitted to the cloud.

These advantages make Edge Computing a robust solution for various applications that demand efficient, real-time data processing and decision-making. [5]

Edge AI

The highly distributed infrastructure of Edge computing also facilitates bringing the AI processing to the Edge reducing the need to send all raw data to the cloud for model training. This set up supports data anonymization methods such as the Federated Learning proposed by Google® in 2016 [6] in which the Machine Learning (ML) models are trained on Edge nodes and sent to cloud for averaging with other models that can be resent to the decentralized nodes. This type of approach protects the data and enables compression of the digital information sent to the cloud. In this reference document we propose an alternative approach for Computer Vision with AI using on-premises solution for highly secure environment, without the need of a cloud by allowing edge clients to run inference applications while another Edge server is used for training and retraining the models.

Lenovo® ThinkEdge®

The Lenovo ThinkEdge® devices used for the solutions presented in this document offers a range of benefits for the manufacturing applications These benefits include:

- **Rugged Design:** The ability to operate in tough environments, ensuring reliability and durability.
- **High connectivity and input availability:** Small form-factor servers with extensive connectivity options and input availability.
- **High processing capability:** Enhance security measures such as tamper-detection features.
- In addition, the Lenovo® ThinkEdge® servers enable AI model training, data aggregation, and edge note management. Key features include:
 - **Baseboard Management Controller (BMC):** For efficient management of edge nodes.
 - **Enhance Security:** Security features such as locking security bezels and brackets, allowing the server to be used closer to the edge without needing to be in a controlled server room.

These capabilities make Lenovo® ThinkEdge® devices and servers ideal for implementing advanced manufacturing solutions with robust processing, security, and connectivity in challenging environments.

2 Business problem and business value

This section outlines the business problem and the value generated by the Edge solutions for manufacturing. The solutions aim to enhance critical Key Performance Indicators (KPIs) in manufacturing. While these indicators are influenced by external factors such as economics and supply chain dynamics, they are also significantly impacted by internal production-related factors such as equipment availability, maintenance control, quality control, and the agility of process adjustments.

Business problem

One of the fundamental premises for cyber-physical systems, according to the NSF National Science Foundation [7], is to ensure seamless integration with physical elements and computational algorithms. Achieving this integration on the factory shop floor has posed a significant challenge in the digital transformation of manufacturing due to the heterogeneous environment, which includes:

- Hardware
- Communication networks
- Communication protocols
- Operating Systems (OS)
- Application runtimes
- And other components

This diversity makes interoperability the primary challenge in successfully implementing edge computing [8]. Therefore, the question is how to harness the benefits of cloud computing at the Edge, enabling seamless Continuous Integration/Continuous Development (CI/CD) workflow and shared Storage, while also maintaining the low latency and data control of the edge solutions.

Business value

According to Deloitte® research from 2019, the manufacturing sector leads in data creation, as illustrated in Figure 2. This positions the sector with the highest potential for data-driven AI solutions and digitalization.

Annual data creation by industry (petabytes)

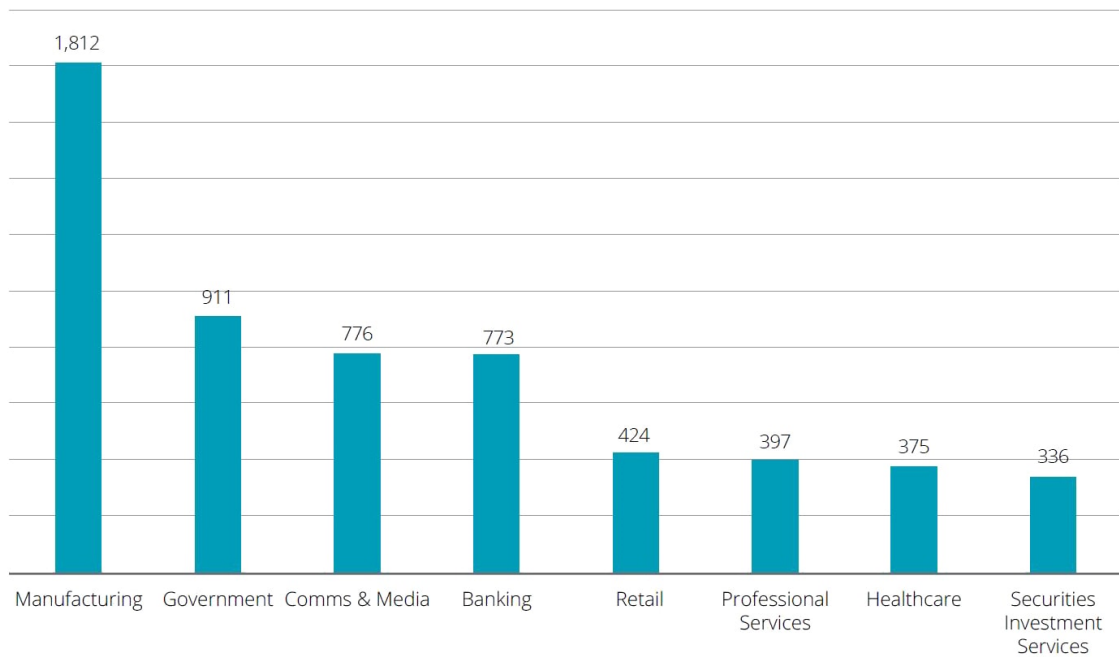


Figure 2 - Volume of annual data per Industry

Source: Deloitte® Survey on AI Adoption in Manufacturing, 2019.

The digitalization can lead to several benefits, including:

- Higher safety and sustainability
- Increased asset efficiency
- Improved product quality
- Reduced production costs

These benefits are highlighted in the Deloitte® 2024 manufacturing industry outlook [9], as illustrated in Figure 3.

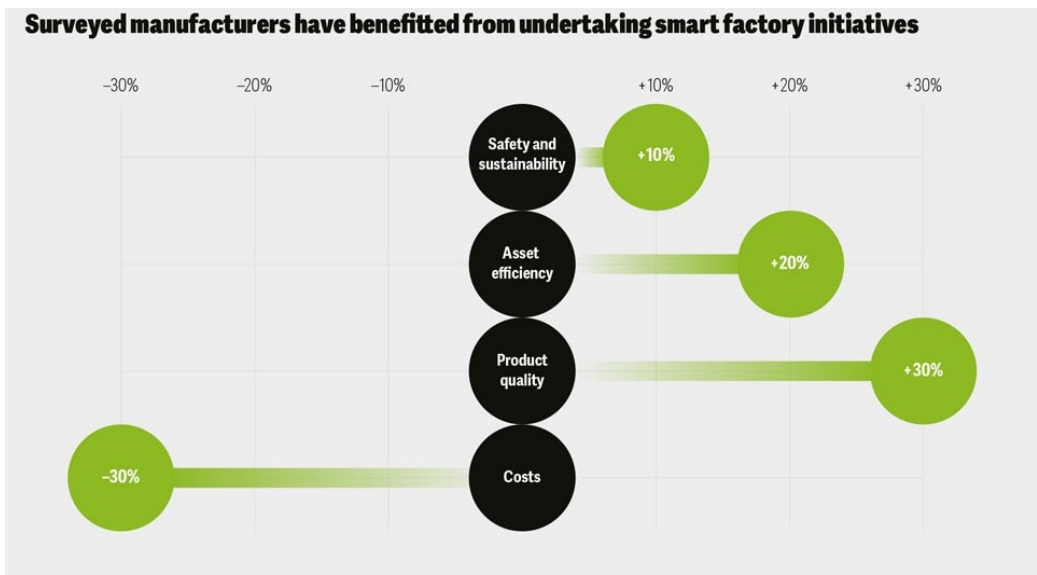


Figure 3 - Benefits of Smart Factory initiatives

Source: 2024 manufacturing Industry Outlook, Deloitte®, 2024

The utilization of automation combined with real-time digitalization in the manufacturing process also leads to significant improvements in Key Performance Indicators (KPIs) for manufacturing process and quality.

According to the 2020 Acatech study titled “Industrie 4.0 Maturity Index, Managing the Digital Transformation of Companies” [10], the steps for Industrie 4.0 are illustrated in Figure 4. The transition from Step 4 to Step 5 requires the addition of predictive capability, which significantly enhances business value by enabling the foresights of process failures before they occur. This predictive capability can be achieved through AI-powered applications running on the edge and/or cloud.

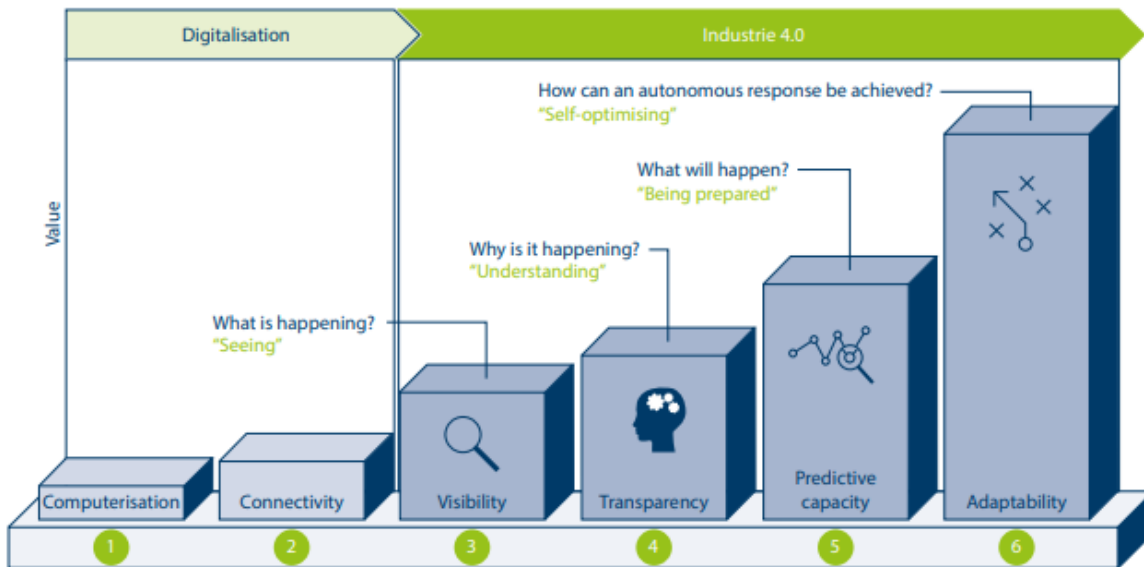


Figure 4 - Stages in the 4.0 Industry development path

Source: FIR e. V. at RWTH Aachen University [10]

3 Goals & Requirements

The solutions presented in this document were designed and validated in a relevant test environment inside Lenovo® Automation Lab in Brazil, utilizing open-source solutions and in-house software development. These solutions were applied to desktop assembling process, focusing on four pillars: automation with AI, IIoT for data collection, digital twin, and automated quality inspection with computer vision, according to Figure 5.

To achieve the validation goals, three robot cells were constructed for automatic memory insertion, CPU insertion and motherboard screwing. All data collected on by the edge clients was transmitted to a ThinkEdge® Server running the in-house Digital Twin Platform. This platform enabled real-time data visualization, predictive maintenance with AI, and production control dashboards. After assembly, the manufactured computers passed through an inspection system using AI computer vision solutions to ensure process quality, also running on ThinkEdge® devices.

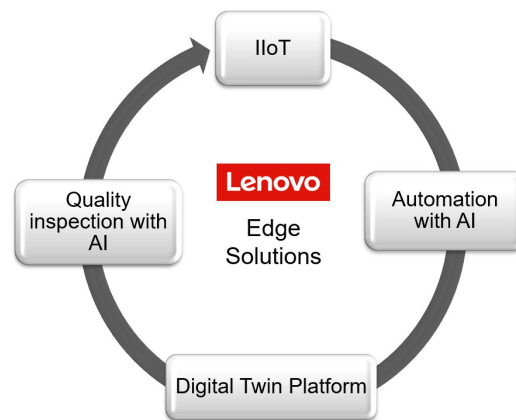


Figure 5 - Goals of the manufacturing solutions

Functional requirements

For the automation solutions, the robot cells were built as shown on Figure 6. The overall equipment is listed on Table 1.

Automation specific requirements:

- Strict response time requirements:
 - Cycle time of each assembling cell cannot be reduced by the monitoring process
 - Aligned with the manufacturing target KPIs, necessitating low-latency data collection and processing at the Edge.
- Robots Indexing:
 - Utilizing computer vision processed at the edge for precise indexing of robots without the need of specific fixture mechanisms for each different assembled product.
- Security Monitoring:

- Continuous monitoring of the robot cell safety at the Edge with quick response time.
- Robot operation is switched-off when doors are opened.
- HMI (Human Machine Interface)
 - Touchscreen monitors for easier configuration of Node-red Instance running on SE30.
 - Safety buttons and lightning for operators



Figure 6 - Automated Robot cells inside Lenovo® Brazil Manufacturing

Table 1 - List of equipment in each robot cell

Equipment used for Validation	Application
ThinkEdge SE30	Edge processing
Epson C8 robot + controller RC700	Automation
Epson CV2	Computer Vision
Epson PC Vision Software	Computer Vision
Epson RC 7.0+ Software	Robot Control
Epson 5MP Industrial IP Camera	Robot arm computer vision
Basler 20MP industrial IP Camera	Robot cell computer vision

The Lenovo® ThinkEdge® SE30 shown on Figure 7 was configured according to Table 2.



1. Power connector	8. Power button
2. HDMI (for Celeron, i3) / DisplayPort (for i5)	9. Serial
3. USB 3.2 Gen 2	10. Serial
4. Thunderbolt 4	11. USB-C 3.2 Gen 2
5. Ethernet (RJ-45)	12. USB 3.2 Gen 2
6. Ethernet (RJ-45)	13. USB 3.2 Gen 2
7. Kensington Security Slot	14. Headphone / microphone combo jack (3.5mm)

Figure 7 - Lenovo® ThinkEdge® SE30

Table 2 - Lenovo ThinkEdge SE30 configuration

Item	Description
CPU	Intel® Core™ i5 vPro 11th Gen S2(C/L)
SSD	256GB SSD M.2 2230 PCIe® 3.0 NVMe®
RAM memory	16GB DDR4-3200 soldered memory
Operational System	W10 IoT 2021 LTSC Value DPK WW
Ethernet	Gigabit Ethernet (Realtek® RTL8111KI) and 2.5 Gigabit Ethernet (Intel® I225)
Graphics	Integrated Intel® Iris® Xe Graphics
WLAN + Bluetooth	Intel® 9260, Wi-Fi® 5, 802.11ac 2x2 + BT5.1, vPro®
Power Adapter	65W 89% Adapter
Dimension	179 x 88 x 51.5 mm (7.05 x 3.46 x 2.03 inches)

IIoT / Digital Twin specific requirements:

- Real-time data collection from robots transmitted to the platform using the MQTT (Message Queuing Telemetry Transport) protocol.

- Data collection, processing, and storage implemented exclusively with on-premises solutions.
- Real-time representation of the physical process through 3D visualization.
- Datalake repository enabling AI applications, such as predictive maintenance.

Data aggregation and processing for the Digital Twin platform were implemented on the ThinkEdge® SE450, configured as Table 3 and depicted in Figure 8



Figure 8 - ThinkEdge® SE450

Table 3 - ThinkEdge® SE450 configuration

ThinkEdge SE450 (7D8TCT01WW)	Qty
Intel® Xeon® Silver 4314 @2.40GHz 16C/32T	1
ThinkSystem® 32GB TruDDR4 3200 MHz (2Rx4 1.2V) RDIMM	4
SSD M.2 5300 960GB SATA NHS SSD	2
SSD SATA 480GB	2
GPU, Nvidia®, Ampere A2, PCIe, 16GB, 40W, half length, passive cooling, graphic GPU	1
Chassis 2U 300mm	1

Quality inspection requirements:

The AI developed includes inspections and detection capabilities:

- Label inspection – Verify that correct label is placed according to the Product Structure
- Keyboard inspection
- Screw detection – Check that all screws are placed correct and in the right place.

For this task the list of equipment used is according to Table 4

Table 4 - Equipment for quality inspection

Equipment used for Validation	Application
Lenovo® ThinkEdge® SE30	model inference
Lenovo® ThinkEdge® SE450	Model training
Camera	Image acquisition
PyTorch	Model training
LabVIEW® Application	Front-end

Non-functional requirements

In addition to the functional requirements, several non-functional requirements were considered to ensure the performance, usability, security, privacy, maintainability, and manageability of the solutions. These include:

Table 5 - Non-Functional requirements

Requirement	Description
Scalability	The automation / IIoT solution with digital twin must enable users to add new equipment to the platform for monitoring with ease. This includes the deployment of new Edge clients for data collection. For the Quality inspection, all models retrained with images captured by one node must be replicated across all Edge clients. This ensures that new nodes can be easily integrated to the system, maintaining consistency and accuracy in inspections.
Physical footprint	The selected Edge solutions must have a small footprint to fit seamlessly within the robot cells and the quality inspection workbench.
Ease of installation	Reduced complexity for Edge / automation deployment. The use of Docker and Portainer simplifies the installation of the Edge nodes. This setup allows for easy management through a virtual machine (VM) running on the server.
Ease of management/operations	Portainer reduces complexity of managing Docker containers, allowing for efficient oversight and operations. The system supports self-updating of application and AI models through the network, ensuring the latest versions are always in use.
Security	Edge devices are equipped with tamper detection and locking mechanisms to prevent unauthorized access and intrusion. On-premise

	<p>solution with all Edge clients isolated from the external network. MQTT broker secured on the Edge server</p> <p>LDAP password authentication with Keycloak, Network Access Control (NAC) with zero-trust policy, HTTPS certificate.</p>
High performance	<p>The response time of the automation and AI inspection must be minimized to meet the stringent requirements of each assembly and inspection operation.</p>

4 Design Overview

This section provides an in-depth description of how the solutions were designed for meeting the listed requirements. It also offers a reference design for similar solutions for manufacturing, utilizing on-premises setups and open-source software.

IloT/ Digital Twin Architecture

The designed solution architecture for the data collection and Digital Twin Platform is structured as shown in Figure 9. This architecture provides an OT/IT (Operational Technology / Information Technology) convergence where data collected by the Lenovo® ThinkEdge® SE30s is processed and standardized via MQTT. The data is then sent to the ThinkEdge® Server SE450 for the digital twin visualization, historical data management, and integration with other manufacturing applications.

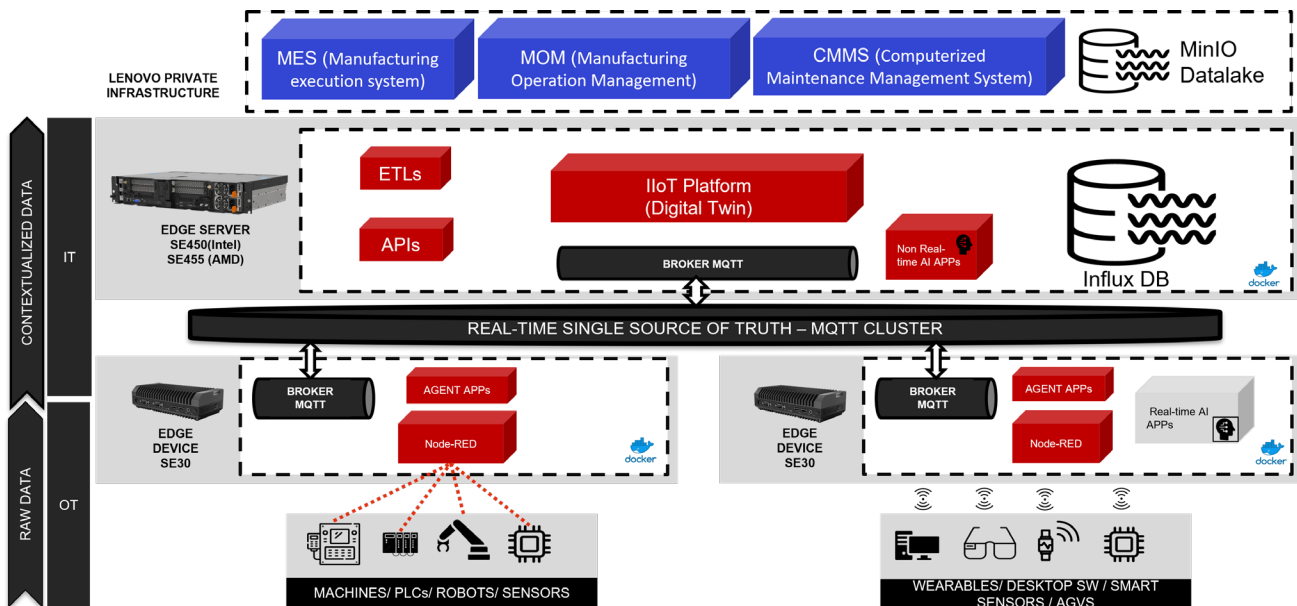


Figure 9 - Project Architecture

The specific modules used were the following:

- **Node-RED:** A low-code tool for connecting hardware devices and APIs, facilitating data collection and transformation. Ideal for bridging operational technology (OT) and information technology (IT).
- **MQTT Cluster:** Centralizes and democratizes the real-time values of all data points, avoiding point-to-point integration and enabling real-time data exchange. Acts as a single source of truth for the current state of the shop floor. The developed solution used EMQX open-source solution for validation.
- **InfluxDB:** An open-source time-series data platform for storing historical values of all data points, supporting big data analytics.
- **IloT Platform:** Focuses on device and asset management, including maintenance control, real-time data analysis, and control.

- **MinIO Datalake:** Perfect for centralizing and democratizing data for AI and business intelligence applications.

IloT/Digital Twin Dataflow

As illustrated in Figure 10, the dataflow of this application involves each SE30 in the robot cells are being used for data collection and edge processing of signals coming from the Epson® RC700 robot controller. All data is aggregated on the SE450 for data storage and digital Twin commands. This setup also enables further AI applications with historical data, such as predictive maintenance, as a key step towards advancing Industry 4.0.

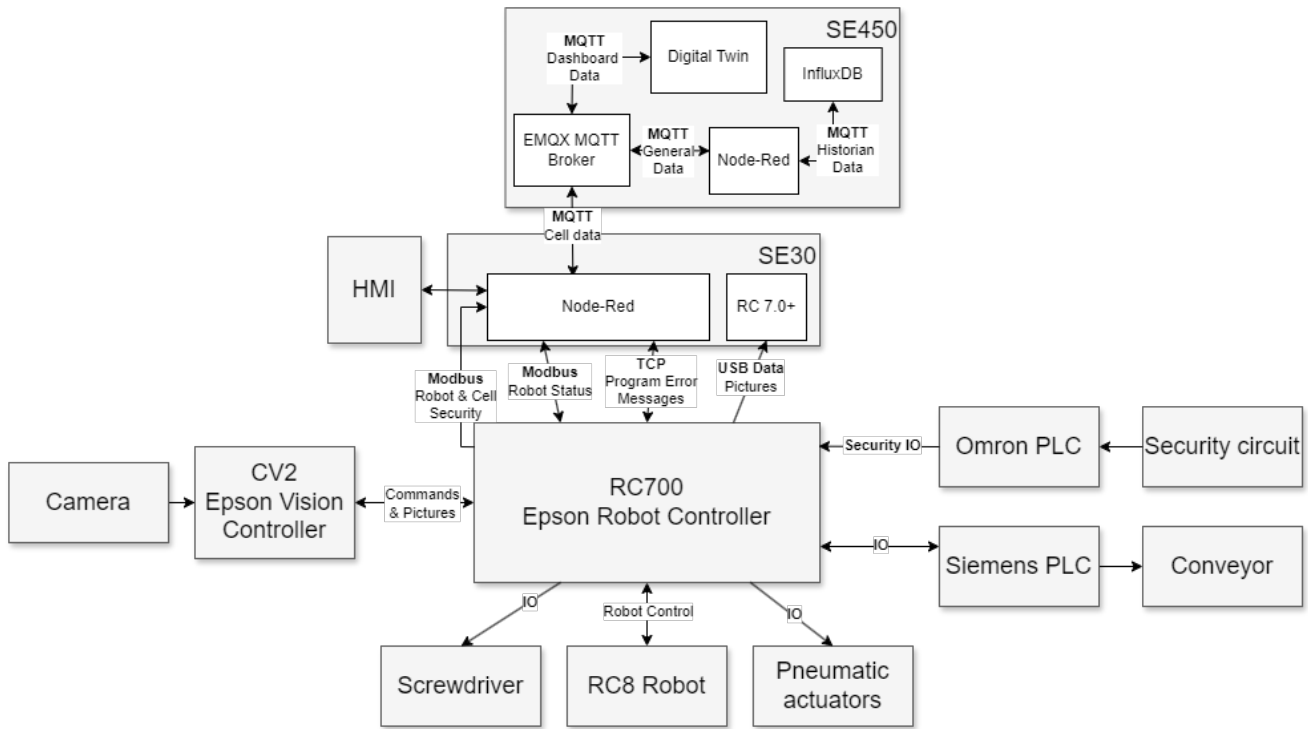


Figure 10 - IloT dataflow

AI quality inspection

The AI-powered quality inspection is trained for each computer model assembled, enabling it to detect assembly process failures. The SE450 is used for training the model with PyTorch. All the SE30's clients are running the inference process using a Lenovo's custom application developed with PyTorch featuring a LabVIEW® front-end. The system architecture is configured as shown in Figure 11.

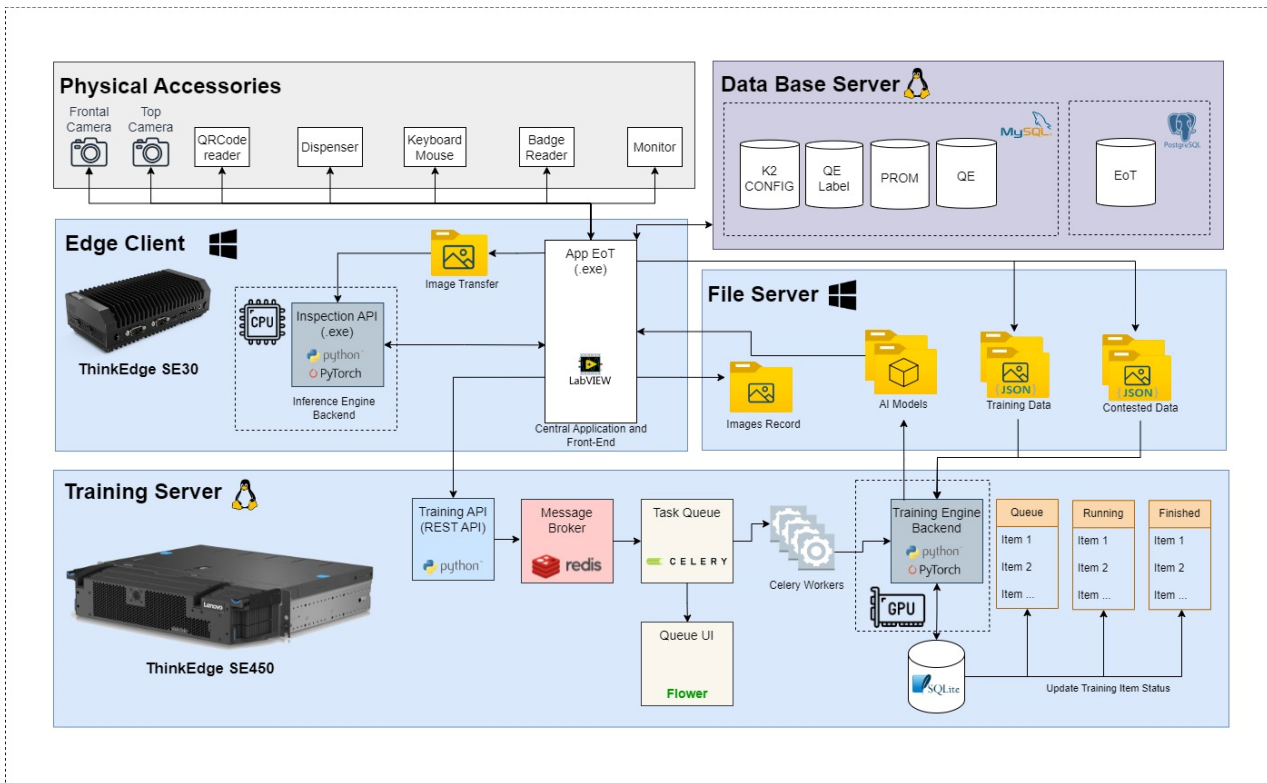


Figure 11 - Quality Inspection Architecture

Quality Inspection Dataflow

Images are taken and processed directly on the Edge for each manufacturing line. The results are displayed on a monitor, used as HMI for each line. In the event of a false-negative result, the operator can tag the image correctly and send it for retraining on the SE450 server. Once trained, the updated model is replicated to the others SE30 clients, ensuring they use the new model. This data flow is depicted in Figure 12.

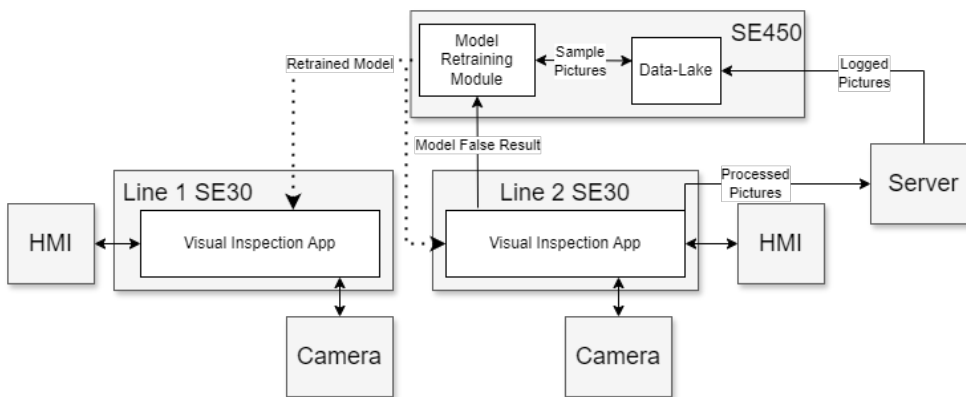


Figure 12 - Quality Inspection with AI dataflow

5 Deployment Infrastructure

The infrastructure view of the Server/Client applications and management solution implement is shown in Figure 13. The OT solutions are deployed on the ThinkEdge® SE30 devices using docker containerized images and monitored from the ThinkEdge® SE450 using Portainer with the management Virtual Machine (VM). All VMs installed in the SE450, as detailed in the picture, are virtualized, and monitored with Proxmox hypervisor. The setup includes:

- **Management VM:** Manages the Edge Clients' containerized images though Docker/Portainer
- **IIoT VM:** Collects IoT Data from the Edge Nodes and aggregates the information for Digital Twin visualization.
- **Datalake VM:** Aggregate Data for object storage with MinIO.
- **AI Training VM:** Trains new models or retrains existing models for the AI quality inspection solutions.

On the OT side, the ThinkEdge® SE30 run Node-Red for IoT Data Collection or the proprietary AI solution for the quality inspection.

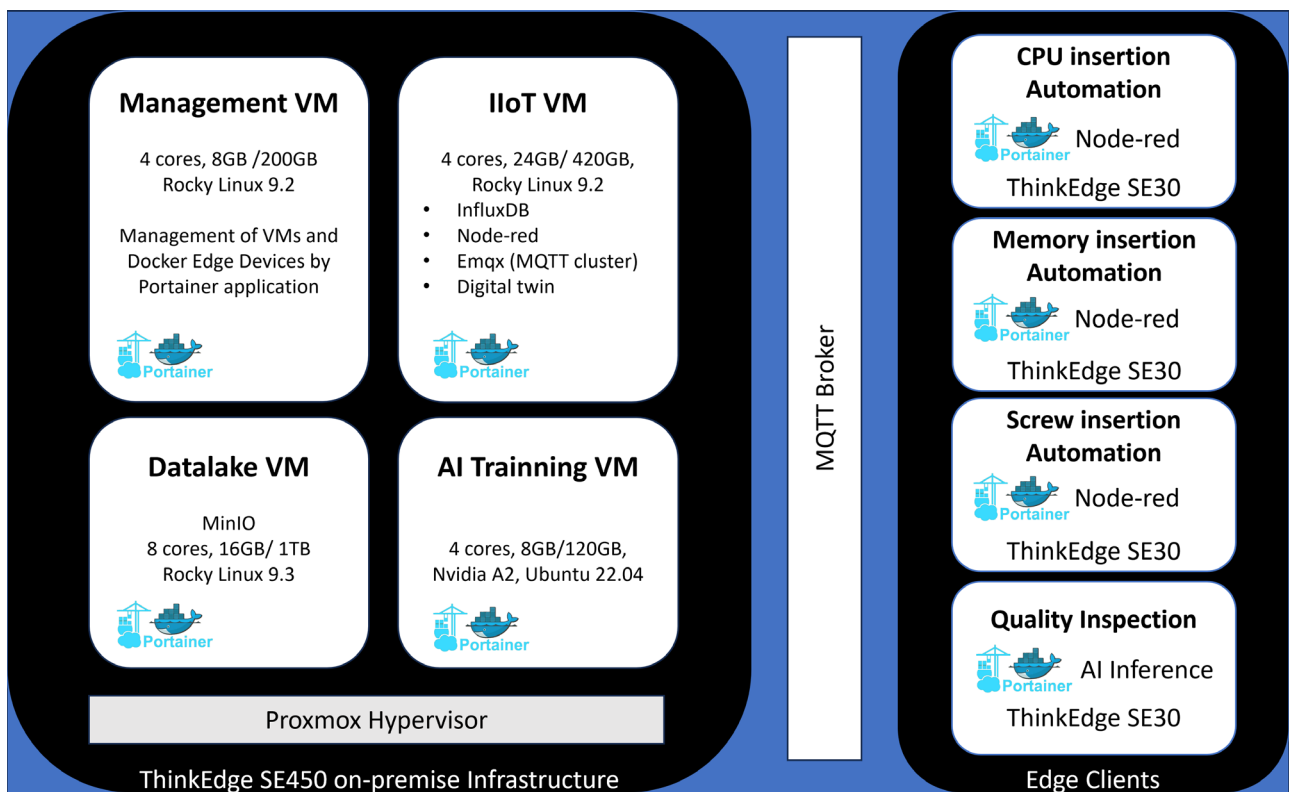


Figure 13 - Server and client infrastructure

6 Deployment considerations

The specific configurations required for the server, compute nodes and infrastructure are described below:

Systems management

The deployment of containers on client machines is managed via a dedicated VM using Docker and Portainer, ensuring streamlined configuration and oversight. All images and containers are securely stored in a GitLab repository for backup and version control. In the second phase, we will implement clustering for the SE450, which will enhance disaster recovery capabilities and simplify management.

Server / Compute Nodes

The SE450, equipped with a hypervisor solution will host the VMs configured as outlined in the previous chapter. Physical connections between the SE30 devices and the OT equipment can be established via ethernet cable or RS232/RS485 connection, with BIOS configured to support these interfaces. Additionally, to ensure accurate quality inspection, it's crucial to properly position the camera and optimize lighting conditions.

Networking

All devices are connected through CAT-6 LAN cable, forming a tree-topology network, with the SE450 serving as the central hub to aggregate the data from all Edge Nodes. The SE450 also interfaces with other manufacturing servers, enabling seamless integration with applications such as the Manufacturing Execution System (MES)

Storage integration

Given the stringent on-premises requirements of the developed solutions, local storage is shared by the applications and installed directly on the SE450.

Performance considerations

Performance and sizing consideration include latency requirements for data collection. In validated scenarios, a cabled LAN was selected to better stability and safety. However, the SE30 and SE450 also support WLAN or WWAN, offering high-speed and low-latency performance without the need for cabling. For each specific use case, the storage sizing needs to be determined based on the number of nodes, file sizes, and retention policy.

For the quality inspection with AI, the following considerations are important:

- **Training Request:** The number of simultaneous nodes sending training requests to the SE450 must be factored in.
- **AI inference:** The SE30 was selected for inference due to its alignments with the project's requirements.

- **Model training:** An Nvidia® A2 GPU was selected for initial validation. For scenarios requiring faster response times, more powerful GPUs, such as Nvidia® L4 or larger GPUs with the 360mm chassis version of the SE450 should be considered.

7 Solution Validation

For the validation of the Digital Twin solution, the 3D model of the Lab was built within the in-house developed platform. Data collected through MQTT from the SE30 devices connected to the robots was sent to the platform in real-time, enabling easy visualization of the robots' status. Additionally, the other flow of commands from the digital platform to the robots was validated. This validation is illustrated in Figure 14. The high computing power of the SE30 resulted in low latency for data collection and processing.

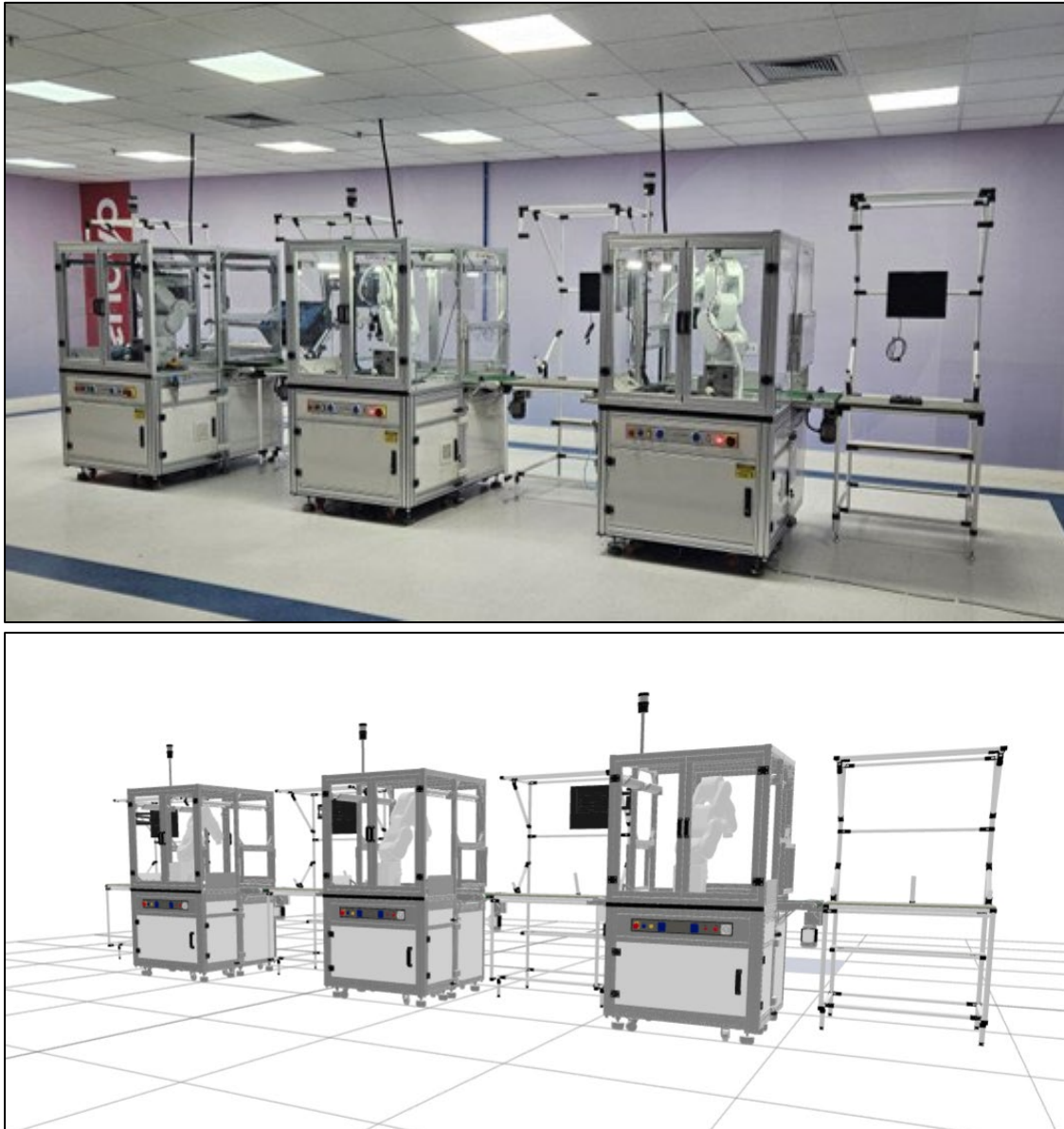


Figure 14 - Digital Twin view (a)Physical view (b)Cyber view

Quality inspection system validation

The quality inspection system was validated based on the application's response time and the accuracy of the AI inspection. The response time of the application was tested with different hardware configurations. The result achieved with the SE30 (Intel® Core i5™, 16GBRAM) demonstrated that the inspections for labels, screw & keyboard using images captured from three different faces of the product (lid open "A3", back cover "C" and lid closed "A1") could be performed in 6,2 seconds. This duration includes the images acquisition, application requisition, and AI inference, meeting the requirements for the quality inspection response time. Results are displayed in Figure 15

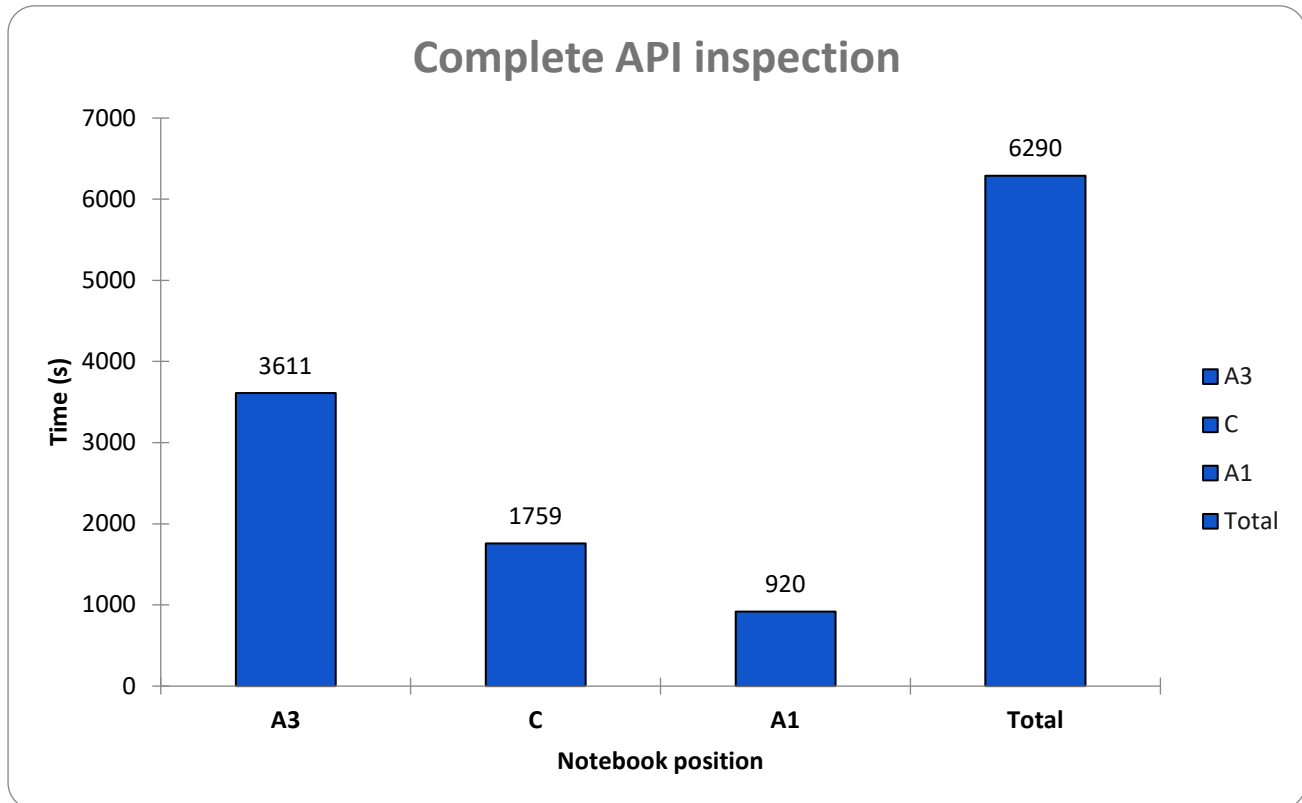


Figure 15 - Inspection time response.

Accuracy of the Quality Inspection System

The Label inspection task was considered the most critical for system accuracy due to the similarity of labels and the variability in images caused by lightning conditions. For validation, the solution was trained using 45.903 images and test with 6.534 images, including labels from Intel®, and other hardware and technology vendors. The AI achieved a mean accuracy of 98.77% for most labels, with 100% accuracy for most Intel® and AMD® labels. The lowest accuracy was observed with Windows® holographic labels due to the angular lightning variance.

The results for the label inspection are displayed in Figure 16 showing two labels properly detected with 100% accuracy.

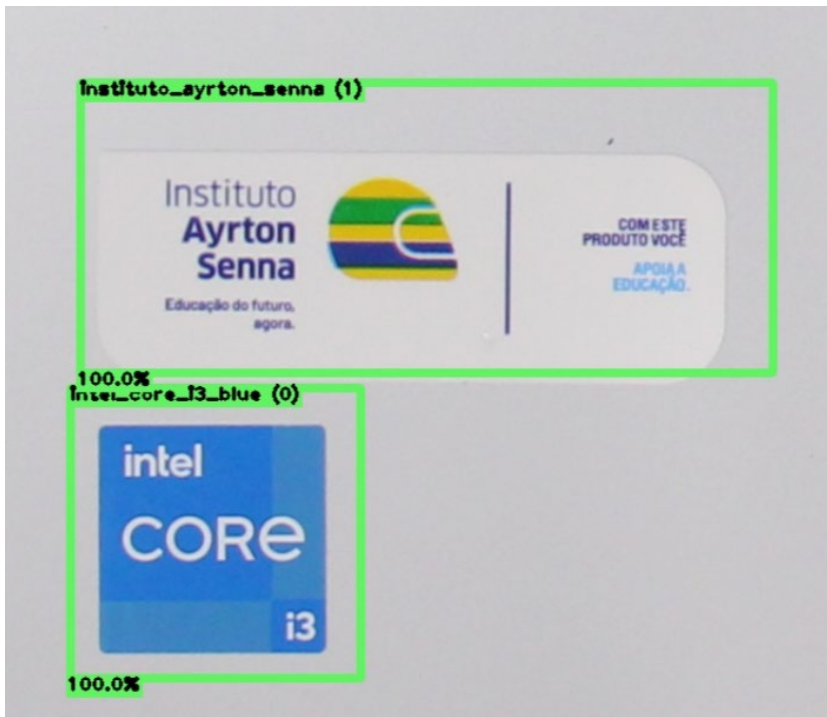


Figure 16 - Label Inspection validation

The results for keyboard inspection are shown in Figure 17 and the screw detection is displayed in Figure 18.



Figure 17 - Keyboard inspection



Figure 18 - Screw detection

8 Appendix: Bill of materials

This appendix contains the bill of materials (BOMs) for different configurations of hardware for Smart Manufacturing deployments. There are sections for user servers, management servers, storage, and networking.

The BOM lists in this appendix are not meant to be exhaustive and should always be verified using the appropriate configuration tools. Any discussion of pricing, support, and maintenance options are beyond the scope of this document.

Within a specific BOM section, optional items are numbered with alternatives shown as lower-case letters. For example, a Fibre Channel adapter for a compute server is only needed for shared storage connected through a SAN.

BOM for compute servers

For the SE30, the following options apply to the bill of materials:

Table 6 - SE30 BOM

Part Number	Material Description	Qty
11NB001BBP	Desktop TE SE30 I51145V 16G 256G W10IOT	
SBB1K34463	UL Warning C/L LBL BK	1
SBB1K34467	UL Warning P/L LBL M_BR2032	1
SBB1N66732	UL4200A Flyer Non-CRU BR2032	1
SBB1A24125	Back Cover w/o Heatpipe DP	1
SBB0G92499	Line Cord C5 Brazil	1
SBB1A18981	SG ENG/BRL/ARA/FRA/SPA	1
SBB1A24085	65W 89% Adapter BK -20~60C	1
SBB0F52821	MEXICO NOM MARK CARTON LABEL	1
SBB0L54571	USB TRDTNL KB BK BRL	1
SBB0T14030	High temp Warning LBL	1
SBB1K29603	Italy Env label	1
SBB1K39001	PUB BRL	1
SBB0X40698	W10 IOT LTSC21-BRL	1
SBB1B50567	9260NGW LBL OEM ZAF	1
SBB0L52928	USB Calliope Mouse BK	1
SBB1A23859	0.81L TGL-U Fanless	1
SBB0T14540	Ukraine Carton Label	1
SBB1B55142	MFG printing LBL OEM	1
SBB0K62289	China CCC mark carton LBL MTY	1
SBB1B49551	EQM mark label(P/L)	1
SBB0T14664	MI system LBL 65W Adapter WT	1
SBB0T14627	Carton label for Nano	1
SBB1A23971	USB-C to HDMI 0~50C	1

SBB0T20235	A 65W adapter India BIS LBL	1
SBB1A24467	Russia CU Cert lbl Tiny	1
SBB1A23887	256GB SSD M.2 2230 NVMe TLC	1
SBB0G92313	CEL Category D	1
SBB1B51699	Core i5 vPro 11th Gen S2(C/L)	1
SBB1A24134	5B20U54711 MB FRU IOT DPK	1
SBB1B54862	MI for Industrial Computer(C/L)	1
SBB1B50566	9260NGW Printing LBL OEM	1
SBB0M47608	Win10 IoT Enterprise Flag	1
SBB1B50370	9260NGW LBL UAE	1
SBB1A23853	TGL-U I5-1145GRE vPro+16G DP	1
SBB1A24078	Intel 9260 2X2AC+BT vPro WW	1
SBB0T18348	India BIS Label	1
SBB0T16881	Carton label Nano OEM	1
SBB1H10111	France_TRIMAN label(P/L)	1
SBB1B50680	9260NGW LBL BRL	1
SBB0T14628	System LBL BK for Nano	1
SBB1K32866	Dummy Israel Importer Label	1
SBB1A23874	15W Cooler Kit	1
SBB1A22774	Enable tpm key	1
SBB0T14539	Taiwan New Label	1
SBB0F52822	European CE Mark For Carton Label	1
SBB1B50425	9260NGW Carton LBL OEM	1
SBB0T14751	China CCC Mark Carton Label	1
SBB1F35175	W10 IoT 2021 LTSC Value DPK WW	1
SBB0J03224	CEL EG1 Label	1
SBB1B49841	PKG w/ TRDTNL KYB FNL WW	1

SE450 Bill of Materials Options:

Table 7 - SE450 BOM

Material	Material Description	Qty
0000000-FN496	LABEL Label GBM	2
0000000-NC817	PACKAGING Label BOM	1
0000000-WG047	PACKAGING Dist label GBM	1
0000000-Y7997	PACKAGING 1200x600mm Pallet	1
0000000-Y8535	PACKAGING 1200x600 Pallet BOM	1
0000000-YD664	L1 MI USB slave	1
SG27B23467	GPU, Nvidia®, Ampere A2, PCIe, 16GB, 40W, half length, passive cooling, graphic GPU	1

SBB7A18-236	L1 SP ICX Intel® 4314 16C/2.4G/135W	1
SBB7A18-398	L1 SM 32GB 3200MHz 2RX4 1.2V RDIMM	4
0000001-DC058	TAPE PKG Hand Tape	0,01
0000001-DC058	TAPE PKG Hand Tape	0.008333
0000001-R3797	PACKAGING 5*51*51*521mm-90EdgePrct	4
0000006-P6550	PACKAGING tamper label	1
0000013-J2919	PACKAGING C.P	0
0000020-P0566	PACKAGING IRON BUCKLE	0
0000024-L0548	L1 MI DUMMY 000xxxx	2
0000026-K6042	SCREW M3x3 PHILLIPS	8
0000027-F4212	SCREW M 3.5 STEEL	3
0000027-F4212	SCREW M 3.5 STEEL	4
0000037-L7558	PACKAGING sanstrap	3
0000039-M5508	LINECORD JCord - 2M	2
0000041-H8524	PACKAGING IBM LOGO	0.166667
0000041-Y5557	PACKAGING IRON BUCKLE	0.166667
0000043-X3129	PACKAGING CTN Label 4x6	0
0000043-X3177	PACKAGING 5*50*50*826mm-90EdgePrct	0
0000043-X3229	PACKAGING corner protect	0
0000044-E1939	PACKAGING stretch wrap	0.166667
0000044-E1942	LABEL Carton label	2
0000046-C7465	L1 PWRC 2.0M, 13A/125V	2
0000046-D2194	PACKAGING Corner Protect	4
0000068-Y7397	L1 MI SELECT STORAGE	1
0000081-Y7879	LABEL Mfg Proc Lbl	1
0000095-Y4095	L1 MI_P CONF ID 01	1
0000095-Y4137	L1 MI_P CONTRLR 01	1
0000095-Y4825	GBM Memory Labels	2
0000095-Y4828	LABEL MemoryLabeling	2
SB27B02-967	BDPLANAR Bona Edge Planar ASM PASS6 R2	1
SBB7A01-422	L1 LPK WW Lenovo LPK	1
SBB7A01-520	L1 STA M.2 SATA/NVMe 2-Bay Kit	1
SBB7A02-980	L1 MI OB SATA RAID mode	1
SBB7A03-309	L1 HSK SR630 V2 Std Heatsink	1
SBB7A03-864	L1 FOD XCC Advanced to Enterprise	1
SBB7A14-753	L1 MECH POWER PADDLE SR850V2	1
SBB7A18-205	L1 MI Disable IPMI-over-LAN	1
SBB7A18-652	L1 MI SE350 Disable IPMI-over-KCS	1
SBB7A18-683	L1 MI Security Pack Disabled	1
SBB7A20-356	L1 CPK Brazil CPK	1
SBB7A20-707	L1 COPT ThinkSystem 4R CPU ICX HS clip	1

SBB7A21-643	L1 MI N+N redundancy with OVS	1
SBB7A35-835	L1 PKG Bona Standard PKG BOM L1	1
SBB7A41-303	L1 MI Efficiency - Favor Performance	1
SBB7A43-710	L1 HD Intel S4520 480GB SATA SSD	2
SBB7A14-832	SSD M.2 5300 960GB SATA NHS SSD	2
SBB7A44-555	L1 MI Low voltage (100V+)	1
SBB7A45-867	L1 PS Edge 1100WP AC PSU	2
SBB7A50-449	L1 CA Intel I350 OCP w/ Internal Lock	1
SBB7A50-453	L1 BASE BONA_2U_CHASSIS_ASSY-300	1
SBB7A50-456	L1 MECH FAN MODULE ASM	6
SBB7A50-460	L1 MECH Bona Edge Left Riser PCBA Cage	1
SBB7A50-461	L1 MECH Bona Edge Right Riser PCBA Cage	1
SBB7A50-469	L1 COPT L300_2U-TO-1U_HS_FILLER_ROSA	1
SBB7A50-474	L1 COPT BONA_PDB_COVER	1
SBB7A50-476	L1 COPT BONA DETECT MODULE FILLER	1
SBB7A50-480	L1 MECH REAR ANT BOX FILLER	2
SBB7A50-482	L1 MECH OCP_CAGE	1
SBB7A50-483	L1 MECH OCP_CABLE_BRACKET	1
SBB7A50-484	L1 MECH BONA_2U_SSD_CAGE	1
SBB7A50-488	L1 MECH BONA_TOP_COVER_LED	1
SBB7A50-492	L1 MB Bona Edge System Planar	1
SBB7A50-493	L1 MECH Kepler-OPN RoT Module	1
SBB7A50-498	L1 COPT Label Group	1
SBB7A50-514	L1 CBL SE450 Internl 2x1 SATA Cable	1
SBB7A50-518	L1 CBL SE450 Riser PCIe x8 Cable	2
SBB7A50-611	L1 MECH BE SBS M.2 ADAPTER BRACKET	1
SBB7A50-613	L1 MECH SE450 Port Dust Cover Kit	1
SBB7A50-620	L1 CBL SE450 PDB Sideband Cable	1
SBB7A50-622	L1 CBL SE450 M.2 Adapter Cable	1
SBB7A50-624	L1 LBL Bona Edge Service Label LI	1
SBB7A50-771	L1 LBL Bona Edge Agency Label	1
SBB7A50-774	L1 LBL Bona AC 1100W PR. ROW Label	1
SBB7A50-779	L1 LBL Bona Edge OCP 4P Label	1
SBB7A54-938	L1 MI TPM 2.0 & non-PFR Sec Function	1
SBB7A64-573	L1 REGID E2201	1
SC17B03-357	CABLE SATA Cable C for 2*2.5"HDD w/BP	1
SC17B03-361	CABLE Riser PCIeI Cable	2
SC17B03-378	CABLE Led Cable for Wall Mount	1
SC17B05-132	CABLE OCP Cable	1
SC17B05-141	CABLE PSU Signal Cable	1
SC17B05-146	CABLE M.2 Cable	1

SC87A98-454	CHASSIS 2U,300MM CHASSIS	1
SG17A10-098	GBM S/N INFO, BLACK	1
SG17A30-791	GBM Label GBM, BLACK AGENCY LABEL	1
SH47A41-755	HEATSINK LGA4189 1U Std HTSK	1
SL17A02-113	LABEL Large Lenovo Label	1
SL17A03-709	LABEL Ribbon for HDD label	2
SL17A03-725	LABEL Lenovo Response label	1
SL17A04-177	LABEL Memory Security label	2
SL17A06-151	LABEL Ribbon artwork DBS 5000	0.166667
SL17A30-639	LABEL RIBBON, SILVER	0.166667
SL17A30-792	LABEL SYS LABEL, BLACK	1
SL17A67-774	LABEL HDD Security label for WTY	2
SL17A98-284	LABEL OCP NIC LABEL 4P	1
SL17A98-287	LABEL THINK EDGE LABEL	1
SL17A98-288	LABEL PDB COVERING LABEL	1
SL17A98-293	LABEL MODEL NAME LABEL	1
SL17A98-302	LABEL AGENCY LABEL	1
SL17B02-845	LABEL POWER SAFETY LABEL 1100W AC	1
SL17B02-851	LABEL SSL LI	1
SM17A65-310	MECH_ASM Europa PDB SVT	1
SM17A98-131	MECH_ASM OCP CABLE BRKT	1
SM17B01-955	MECH_ASM I/O FILLER GBM	1
SM17B02-177	MECH_ASM 1U HS FILLER L300 W/ MYLAR	1
SM17B08-941	MECH_ASM PCI RISER BRACKET LEFT	1
SM17B08-943	MECH_ASM PCI RISER BRACKET RIGHT	1
SM17B08-944	MECH_ASM INTERNAL HDD CAGE	1
SM17B08-948	MECH_ASM 2U OCP COVER CAGE	1
SM17B08-950	MECH_ASM 6056 FAN ASM AVC	6
SM17B08-982	MECH_ASM 2U SBS M2 BRACKET	1
SM17B08-985	MECH_ASM BEZEL DETECT BRKT FILLER	1
SM27A78-111	MECHANICAL Lotes AZIF0193-P001C11	1
SM27A98-171	MECHANICAL PDB SWITCH CAP	1
SM27B09-007	MECHANICAL REAR ANTENNA FILLER	2
SM37A92-787	MEMORY T SMR4WEC4C4K3472SDI D4-32R	2
SMD7A93-000	MTD MAKE TO DUMMY	2
SN37B01-921	NETWRK_CRD Intel OCP, NETWRK_CRD	1
SP17A35-426	PACKAGING 500m Thank you tape	0
SP17A35-426	PACKAGING 500m Thank you tape	0.166667
SP17A69-933	PACKAGING RFID Label	1
SP17A90-031	PACKAGING Bona Standard PKG BOM L2	1
SP17A90-032	PACKAGING Bona Standard PKG BOM L3	1

SP17B02-290	PACKAGING Bona bottom cushion	1
SP17B02-291	PACKAGING Bona top rear cushion	1
SP17B02-292	PACKAGING Bona top front cushion	1
SP17B02-293	PACKAGING Bona SG box	1
SP17B02-294	PACKAGING Form bag	1
SP17B02-295	PACKAGING Bona MTY carton	1
SP47A36-797	PUBS Brazilian Warranty for ThinkSystem	1
SP47A76-666	PUBS DCG Regulatory Notices (Full)	1
SP47B35-788	PUBS ISG epub booklet, GBM	1
SP57A97-080	PWR_SUPPLY Delta 1100WP CFFv4 AC RF PSU	2
SR17A32-463	RAID_CARD M.2 SATA/NVMe 2-Bay Kit	1
SS17A04-246	SCREW M3 X 4.5L w/ Nylok #PH	2
SS17A62-738	SCREW SCREW, M3x5_0.8_flat	1
SS17A98-311	SCREW M3 X 4L W/ NYLOK #PH BLACK	3
SS17A98-311	SCREW M3 X 4L W/ NYLOK #PH BLACK	2
SS17A98-313	SCREW M2.5 X 5L	2
SS17A98-316	SCREW SCREW M2 X 1.8L	2
SS17A98-323	SCREW M3.5 X 4L BLACK NYLOK	2
SSA7A85-924	SP ICX 4314 16C/2.4G/135W	1
SSD7A94-342	SSD_ASM 2.5" S4520 480GB RI SATA TL ASM	2
SSS7A43-185	SSD 2.5" S4520 480GB RI SATA HS L2	2
STA7B09-585	ECAT_TLA SE450 Riser1 PCBA PASS5	1
STA7B09-591	ECAT_TLA SE450 Riser2 PCBA PASS5	1
STA7B09-595	ECAT_TLA Kepler-OPN RoT Module, SVT	1
TEX86US-BCAPT	TE X86 CAPTIVE USB slave	1
TSTEAIR-DUCTS	TE PART AIR DUCTS	1
SA37A47-021	ANTENNA WLAN 2.4/5/6G Antenna	2
SC17B00-767	CABLE Bona WLAN ANT Cable, 305mm, Black	1
SC17B00-768	CABLE Bona WLAN ANT Cable, 620mm, Blue	1
SM27A70-512	MECHANICAL WIFI Module COVER	1
SN37B02-828	NETWRK_CRD Bona ENM Module ASSY	1
SW17A47-039	WIRELESS WLAN-6E/BT combo module	1
SA37A47-021	ANTENNA WLAN 2.4/5/6G Antenna	2
X000063-17267	PACKAGING Stretch Wrap	0
X000073-86000	PACKAGING Plastic Banding	0
X000073-86001	MECHANICAL BAND SEAL	0
X000081-28003	PACKAGING S/WRAP M/C #3	0

9 Abbreviations

Table 8 - Abbreviations

Acronym	Meaning
IoT	Internet of Things
IIoT	Industrial Internet of Things
OS	Operating System
AI	Artificial Intelligence
LVD	Lenovo Validated Design
GPU	Graphic Processing Unit
CPS	Cyber-physical system
ERP	Enterprise Resource Planning
MES	Manufacturing Execution Systems
MOM	Manufacturing Operation Management
PLM	Product Lifecycle Management
EC	Edge Computing
ML	Machine Learning
BMC	Base Management Controller
CI/CD	Continuous Integration/Continuous Development
OEE	Overall Equipment Effectiveness
OT/IT	Operational Technology/Information Technology
RAM	Random Access Memory
VM	Virtualized Machine
IP Camera	Internet Protocol Camera
SSD	Solid State Disk

10 Authors and Contributors

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11 Resources

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