Eco-Central Computing for Warehouse Optimization

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1. Introduction

1.1. Vision (Purpose and Objectives)

Warehouse operations in Small and Medium-sized Manufacturing Companies (SMEs) face growing challenges due to severe labor shortages, rising costs, and increasing demands for efficiency and safety. Efforts to streamline or automate these processes have lagged.

While large global logistics companies have already deployed advanced warehouse automation, SME warehouses often focus on B2B or B2B2C operations. As a result, inventory management tasks are still largely manual, driving up labor costs and making it increasingly difficult to secure a stable workforce.

Full automation is difficult due to the wide variety of items handled. For example, fulfillment warehouses for B2C e-commerce sites handle only products of predetermined sizes, making packaging and handling tasks easier to automate.

(When handling specialized products, they are shipped directly from the manufacturer to the customer, bypassing the fulfillment warehouse.)

However, in warehouses handling a wide variety of products, workers must make judgments and perform packaging and handling tasks according to changes in product specifications.

The purpose of this use case development is to enable SMEs to overcome these challenges in warehouse operations. To achieve this goal, both automation and operational optimization are essential. Solutions must reduce labor costs through efficiency improvements, enhance worker safety in warehouses, reduce the increased energy consumption associated with automation, and align with sustainability goals. Stakeholders such as small and medium-sized enterprises, logistics operators, warehouse workers, shippers, and government agencies seek tangible benefits, including reducing rising labor costs, shortening delivery times, and promoting regional development through the adaption of green energy.

Today's mainstream approach places automation control and AI processing at the edge, typically within robots or local systems. However, edge processing configurations that allocate GPU resources to each robot increase power consumption and operational maintenance costs, and often fail to maximize stakeholder benefits from an economic rationality perspective. Greater economic rationality can be achieved by centralizing AI processing in green data centers.

The low-latency, high-capacity communication enabled by IOWN makes this centralized approach viable.

The low-latency, high-capacity communication enabled by IOWN makes this centralized approach viable. Its high-capacity, low-latency connectivity enables real-time transmission of large volumes of camera data and remote robot control, while dynamic optical paths and energy-efficient infrastructure support scalable operations over long distances.

The objective of the forum's activities for related to this use case is to establish end-to-end system designs for IOWN-enabled smart warehouses that deliver significant economic benefits to warehouse operators.

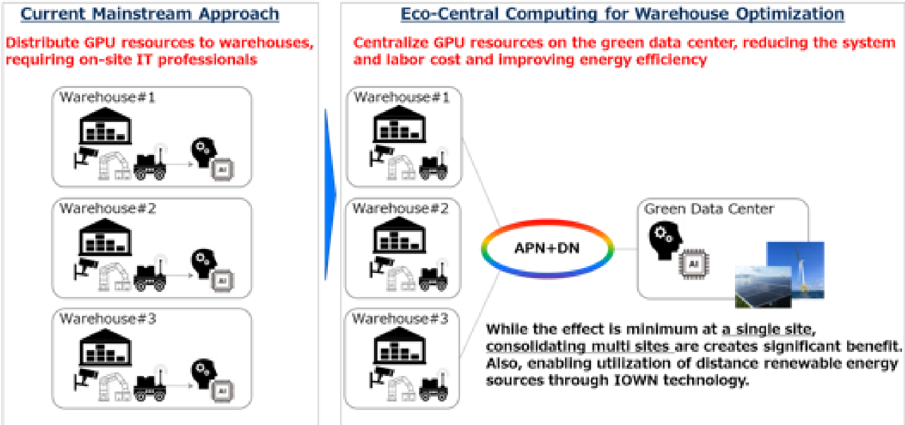

Figure 1.1: Our vision of warehouse system architecture and use cases

1.2. Scope

This document describes the following two points:

- The Use Case and its key requirements
- The Technology Evaluation Criteria

It addresses labor shortages and inefficiencies in warehouse operations for SMEs, by focusing on automation, process optimization, and the use of green energy to improve sustainability. Unlike e-commerce fulfillment centers, the target is manufacturing-related warehouses handling B2B and B2B2C transactions. The scope also explains how IOWN enables high-capacity, low-latency connectivity and energy-efficient infrastructure to support safe, scalable, and environmentally responsible operations.

*E-commerce fulfillment centers:

Companies engaged in e-commerce (B2C) businesses, purchase goods, sell them in large quantities, and generate profits. Handling large volumes of goods requires automation, and their warehouses are designed with automation as a fundamental premise.

*SMEs warehouse:

Manufacturing, and warehouse operations departments are separate from sales teams or retailers who actually sell the products. Since warehouse staff are part of a cost-bearing department that doesn't directly generate profit, automation has been slow to advance. They haven't been able to break away from manual processes inherited from legacy practices (e.g., warehouse equipment).

2. Use Case

This chapter presents three use cases.

- Optimization of human and robot traffic flow (details provided in Section 2.1)
- Automation and safety monitoring in the warehouse (details provided in Section 2.2)
- Automation Using Robots with Remote GPU (details provided in Section 2.3)

A common concept across the use cases is to connect geographically distributed warehouse sites to a Centralized Datacenter (DC) powered by renewable energy via APN, and to execute power-intensive advanced processing. This architecture enables the aggregation of high-power-consuming processes, allowing warehouse operators to concentrate IT resources and personnel at a remote DC, thereby improving operational efficiency and reducing costs. Improving warehouse operational processes accelerates workflows for consignees, transporters, and consigners across the supply chain, faster delivery times. In addition, since DCs with high renewable energy potential are located in rural areas, local governments can benefit from job creation and regional economic revitalization. Furthermore, for the central government, this concept offers a way to achieve the dual goals of promoting economic growth and reducing CO_2 emissions, contributing to the realization of a sustainable society.

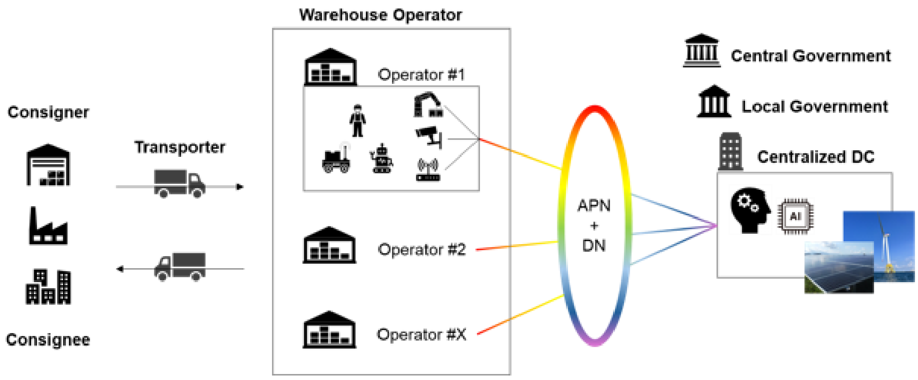

Figure 2.1: Use Cases Overview

2.1. Optimization of human and robot traffic flow

This use case has a key feature that enhances safety and efficiency in human robot collaboration.

The primary focus is on ensuring worker safety. The system detects worker and robot positions from camera footage, enabling accurate location estimation. Using this positional and movement data, it predicts potential future collisions with advanced estimation and collision detection algorithms. When a collision risk is identified, the system promptly issues stop commands to both workers and robots, providing operation guidance and robot control to maintain a safe working environment.

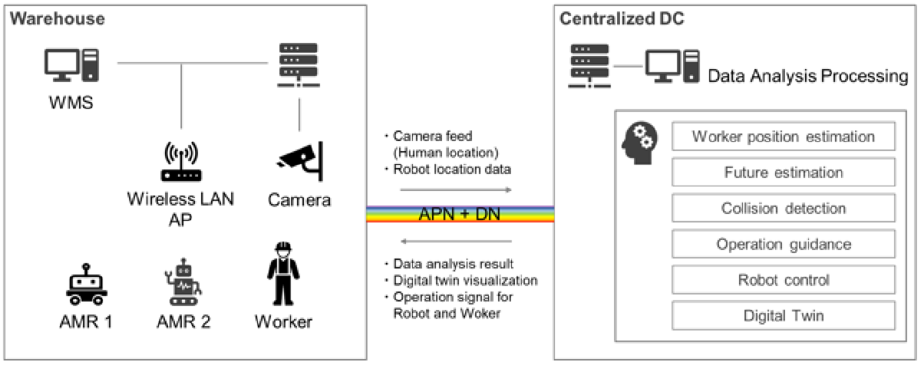

Figure 2.2: *UC1 Overview*

2.2. Automation and safety monitoring in the warehouse

This use case visualizes worker movements.

Multiple camera feeds within the warehouse visualize the movements of people and forklifts.

This visualizes inefficient movements, enabling suggestions for more efficient operations and establishing a system to detect anomalies occurring in the warehouse.

Visualize and monitor personnel movement in real time across large multi-level warehouses to ensure worker safety and support efficient operations.

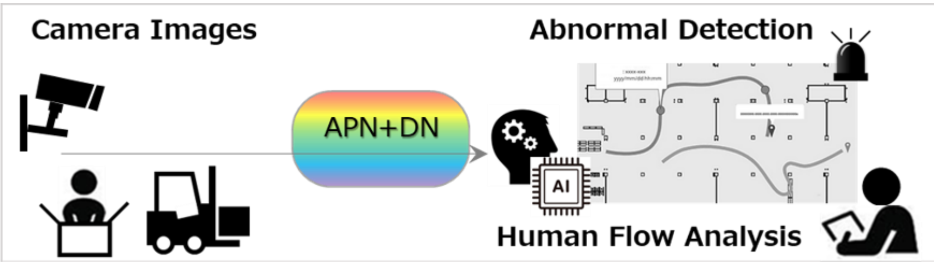

Figure 2.3: UC2 Overview

2.3. Automation Using Robots with Remote GPU

Arm-type robots are being introduced to automate the inspection and processing of incoming goods in warehouses. Arm-type robots automatically execute pre-programmed movements, replacing manual processing and inspection of incoming goods.

GPU servers that control robot movements are located in data centers rather than at the edge.

This allows for efficient GPU processing by consolidating robot control for multiple warehouses in data centers (reducing overall power consumption through consolidation).

It also eliminates the need for server maintenance personnel at each warehouse.

By placing the GPU servers in a green data center powered by 100% renewable energy, the power consumption of the GPU servers is covered by renewable energy.

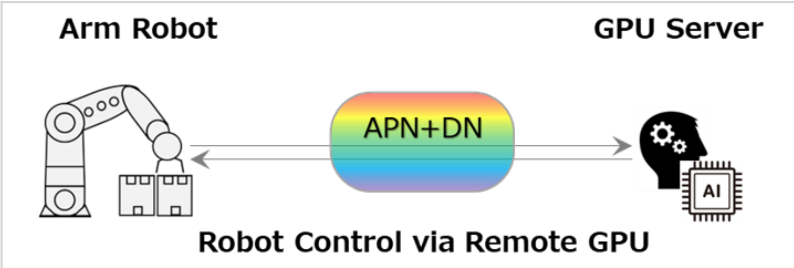

Figure 2.4: UC3 Overview

3. Key Requirements

We present the key requirements for each use case.

3.1. Optimization of human and robot traffic flow

Table 3.1: Key Requirements for UC1

Item	Value	Note
Future prediction time point	3.8s	Future prediction time point is defined as the time horizon (in seconds) by which the system must detect a potential human–robot collision in advance. It is calculated as the sum of the stopping time of the robot operating at maximum speed and the end-to-end processing time as defined below. In the reference case, the robot's maximum speed is 4.9 km/h and its deceleration is 0.5 m/s^2, resulting in a stopping time of about 2.8 seconds. The future prediction time point is obtained by adding this stopping time to the end-to-end processing time. As this time point moves further away, prediction accuracy decreases, so a nearer point is preferable.
End-to-end processing time	1.0 s	This value represents the time from video capture by warehouse cameras to the completion of sending stop commands from the centralized data center to the robots in the warehouse. As stated in the note on the future prediction time point, this value should be kept as short as reasonably possible.

3.2. Automation and safety monitoring in the warehouse

Table 3.2: Key Requirements for UC2

Item	Value	Note
Dashboard Display Latency	1.0 s	Dashboard Display Latency is defined as the latency between camera capture and display on the dashboard.

3.3. Automation Using Robots with Remote GPU

Table 3.3: Key Requirements for UC3

Item	Value	Note
Robot arm processing time	1 min.	Time required for a robot to pick up an item, attach a label, inspect it, and place it in a box.
Control Loop Latency between Robot Arms and Remote GPU	0.1 s	Control Loop Latency is defined as the end-to-end time required for data captured by the robot's cameras and sensors to be transmitted to the control AI, for the control AI to generate control commands, and for those commands to reach the robot. The latency required to control the robot from the GPU server for automated processing.

4. Technology Evaluation Criteria

To evaluate the effectiveness and merits of adopting the IOWN Technologies to realize the use case, we define the Reference case as follows:

4.1. Reference Case for All Use Cases

Table 4.1: Common Benchmark Conditions for All Use Cases

Item	Value	Note
The distance between a local area ware-house and the green data center	Approximately 1,000 Km	e.g. Between Chiba Prefecture and Hokkaido Prefecture
Number of warehouses	10	Target number of consolidation

4.2. Reference Case for Optimization of humans and robots traffic flow

Table 4.2: Benchmark Conditions for UC 1

Item	Value	Note
Work area	22m x 11m	-
Number of Robots	2	At one work area and in the minimal case
Number of Staff	3	At one work area and in the minimal case
Warning method for persons	-	Generate alerts from operational devices such as tablets and smartphones
Number of Cameras	3	At one work area and in the minimal case
Robots Speed	Max 4.9 km/h	Almost the same speed as walking person
Robot deceleration	0.5 m/s^2	-
Data format of Cam-eras	H.265 (Lossy Com-pression)	Millisecond-level video transmission is not re-quired.
Cameras Bitrate	3 Mbps	-
Transmission method	Streaming (RTSP)	-

4.3. Reference Case for Automation and Safety Monitoring

Table 4.3: Benchmark Conditions for UC 2

Item	Value	Note
Visualizing and monitoring method	-	Display of people flow analysis results on the dashboard screen
Warning method for persons	-	Display on the dashboard screen and push notifications to smartphones and other devices
Number of Cameras	20	At one work area and in the minimal case
Data format of Cameras	H.265 (Lossy Compression)	Millisecond-level video transmission is not required.
Cameras Bitrate	3 Mbps	-
Cameras FPS (Frames per second)	5 FPS	-
Transmission method	Streaming (RTSP)	-

4.4. Reference Case for Automation Using Robots with Remote GPU

Table 4.4: Benchmark Conditions for UC 3

Item	Value	Note
Number of Robots	1	Robot body (two arms)
Number of Cameras	2	A camera captures the robot's hand for grasping objects
Processing time per operation	1 min.	Time required for a robot to pick up an item, attach a label, inspect it, and place it in a box.

4.5. Metrics

The following metrics will be used evaluate the developed system.

- NW Latency (for UC #1, UC #3)
- NW throughput and capacity (for UC #2)
- Energy consumption (for All UC)
- Workers' cost (for All UC)
- Computing resources cost (for All UC)
- System maintenance cost (for All UC)
- CO2 Reduction in AI Processing (for All UC)

5. Conclusion

This document presents three use cases for achieving warehouse operational efficiency in manufacturing by leveraging IOWN Global Forum technology.

By combining IOWN's high-capacity, low-latency technology with AI processing powered by renewable energy, it aims to improve operational efficiency, including cost -effectiveness, for manufacturers facing various challenges.

This document outlines the first step in the IOWN Global Forum's activities to engage early adopters in the manufacturing warehouse industry. The Reference Implementation Model and Proof-of-Concept (PoC) Reference document which describes the PoC specification is developed based on this document as a next step.

History

Revision	Release Date	Summary of Changes
1	March 2026	Initial Release