

# Design of an Interactive Visualization System for the Process Workflow of an Intelligent Sub-Assembly Workshop

Peng Liu<sup>1</sup>, Zhuoyi Yang<sup>1</sup>, Dongjiang Yang<sup>2</sup>, Tengfei Sun<sup>1</sup>, Mingkun Guo<sup>3</sup>

<sup>1</sup> School of Naval Architecture and Port Engineering, Shandong Jiaotong University, Weihai 264200, China

<sup>2</sup> Shandong Xinneng Shipbuilding Co., Ltd., Jining 272000, Shandong, China

<sup>3</sup> Weihai Wuchuan Shipbuilding Co., Ltd., Weihai 264200, Shandong, China

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**Abstract:** With the rapid development of intelligent manufacturing in the inland shipbuilding industry, traditional sub-assembly workflows urgently require transformation toward visualization, interactivity, and intelligence. This paper develops an interactive process workflow visualization system based on Unity. The system reconstructs the workshop environment and major equipment through 3D modeling, covering key operations such as steel plate cutting, laser cutting, intelligent sorting, AGV transportation, and welding. Users can select individual operations or the complete workflow via interface controls, enabling autonomous process control and dynamic demonstration. Furthermore, the system integrates a real-time equipment monitoring module, which leverages IoT technology to acquire operational parameters, working states, and performance indicators of critical equipment including laser cutters, welding robots, and AGVs, and presents them in a 3D visualized form. Compared with traditional flowcharts or video demonstrations, the proposed system provides greater intuitiveness and interactivity, supporting applications such as process training, production planning, bottleneck analysis, and equipment monitoring. This approach demonstrates significant application value and potential in process visualization, workforce training, equipment monitoring, and digital twin construction.

**Keywords:** Subassembly Workshop; Process Visualization; Process Modeling; Intelligent Manufacturing.

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## 1. Introduction

With the development of Industry 4.0, industries including shipbuilding and marine engineering equipment are rapidly transitioning toward three-dimensional design and intelligent manufacturing. In this fast-evolving process, the effective implementation of new technologies, novel manufacturing processes, and advanced production management methods on the front line of inland ship production has become a critical component for achieving digitalization and intelligent transformation in the industry [1].

As a key enabling technology for smart manufacturing, digital twin has been widely applied in manufacturing systems. By creating high-fidelity virtual models of physical entities, digital twins enable real-time mapping and interaction between the physical and digital worlds [2]. Before the emergence of digital twin workshops, research outcomes such as digital factories/workshops [3] and production line simulation [4] had already been applied in pre-production workshop layout planning and production line optimization. However, these approaches cannot directly achieve real-time visual monitoring. In recent years, scholars worldwide have conducted extensive research on real-time workshop data acquisition, event-driven monitoring, monitoring models, 3D visualization, and digital twin workshops. For example, in the aspects of workshop data acquisition and event handling, the application of Internet of Things (IoT) technologies [5], especially Radio Frequency Identification (RFID) [6], enables workshops to collect large volumes of real-time production data and generate workshop events through information enrichment. Guangyuan Zhou et al. [7] studied key technologies for visual monitoring of production workshops and developed a platform capable of

real-time, dynamic monitoring of the production process. Wang Zou et al. [8] proposed a data acquisition and management system architecture for manufacturing processes, introducing methods for heterogeneous data collection in workshops. Lei Fang et al. [9] presented a framework for real-time monitoring of production status in digital workshops and developed a corresponding monitoring system.

To support the transformation of inland shipbuilding, and to address challenges in process promotion, personnel training, and production management in the construction of new types of ships, this study proposes and implements a Unity-based interactive visualization system for process workflows. The system restores the workshop environment and key equipment through 3D modeling, covering processes such as steel plate cutting, laser cutting, sorting, AGV transportation, and welding. Interactive buttons allow for demonstration of individual processes or the entire workflow. Additionally, an equipment status real-time monitoring module is integrated, which utilizes IoT to acquire operating parameters and performance indicators of key equipment, including laser cutting machines, welding robots, and AGVs, and visually presents them intuitively within the 3D scene.

## 2. Characteristics of Ship Sub-Assembly Processes

The intermediate products of ship sub-assemblies are typically formed by joining a base plate with one or more ribs arranged in a crosswise manner, as shown in Figure 1. The welding processes involved include flat welding, vertical welding, horizontal fillet welding, and vertical fillet welding. Although the overall structure is relatively simple, the variety of welding types is considerable. In actual construction, this stage often requires substantial human and material resources,

making it one of the more labor-intensive operations in hull

fabrication.

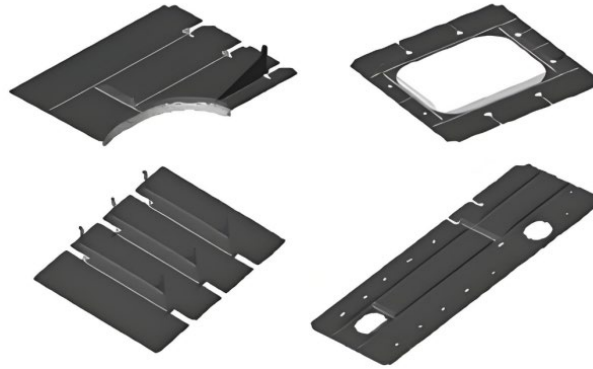


Fig. 1 Typical Ship Sub-Assembly

Sub-assembly production is a crucial stage in ship construction, characterized by parallel segment operations and a high dependence on automated equipment. Ships are typically divided into multiple segments, with different teams simultaneously performing steel plate cutting, segment welding, and assembly. This approach enhances production efficiency but also increases the complexity of process coordination and resource scheduling. Key operations involve automated equipment such as laser cutters, welding robots, and AGVs, which impose stringent requirements on operational accuracy and process control. New employees face challenges in understanding process workflows and mastering equipment operation, as traditional training through 2D drawings and on-site demonstrations is often inefficient and prone to errors. Moreover, variations in process times and equipment constraints exist across different operations. By employing visual simulation and interactive demonstrations, production bottlenecks can be identified, and workflow sequencing and resource allocation can be optimized, thereby improving the controllability and efficiency of sub-assembly production.

### 3. Conventional Sub-Assembly Manufacturing Process Route

The traditional sub-assembly manufacturing process

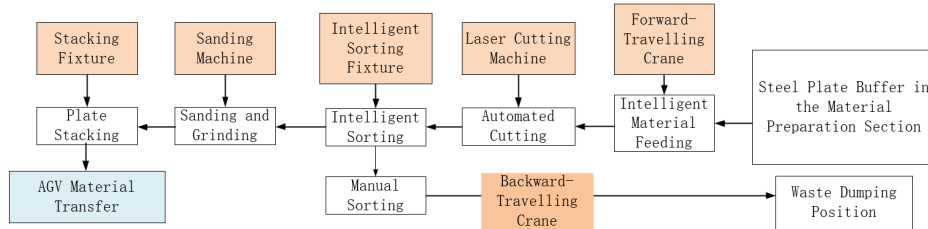


Fig. 2 Intelligent Cutting Production Line for Ship Sub-Assembly

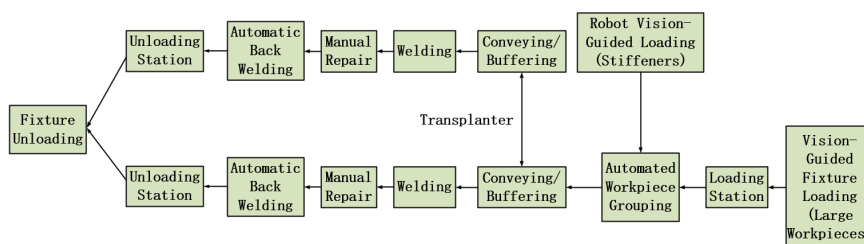


Fig. 3 Intelligent Welding Production Line for Ship Sub-Assembly

#### 4.1. Steel Plate Cutting Process

This process is capable of performing operations such as

primarily includes material feeding, material sorting, panel splicing, assembly, arc welding, grinding and repair, thermal correction, and material output. During the process, steel is first uncoiled from rolls, and the positions of stiffeners are identified and marked. Layout lines are then drawn, and the stiffeners are preliminarily assembled with the plates through tack welding. Subsequently, full welding is performed, followed by back-burning treatment and grinding of the welded areas. Finally, necessary thermal correction is conducted before the material is dispatched. In most Chinese shipyards, manual welding still predominates at the sub-assembly stage, with a low level of automation and a lack of streamlined workflow. As a result, overall production efficiency often falls short of the capacity and schedule requirements of modern shipbuilding enterprises.

### 4. Intelligent Sub-Assembly Workshop and Operational Workflow

By studying the sub-assembly manufacturing process and optimizing its workflow, a linear-layout intelligent sub-assembly production line has been proposed (see Figures 2 and 3). This production line enables intelligent cutting and welding of sub-assembly components, forming a process route for intermediate sub-assembly products oriented toward smart manufacturing.

steel plate cutting, intelligent sorting, automated storage, sanding, and transportation. The detailed workflow is as

follows:

(1) Operators use lifting equipment to transport pre-processed steel plates onto a roller conveyor platform, which conveys the plates to the laser cutting workstation for cutting.

(2) After cutting, the plates are sorted by an intelligent sorting gantry and manually. The sorted plates are then transported to automated storage or to the sanding machine for grinding.

(3) The gantry places the ground plates onto pallets, which are then transferred to the welding workstation by AGV vehicles.

## 4.2. Robotic Welding Process Workflow

This process employs a robotic welding system to achieve automated welding of sub-assembly components, as shown in Figure 4. The detailed workflow is as follows:

(1) Basic positioning is completed by manual tack welding through manholes, after which the irregular sub-assembly automatic feeding system ensures precise material supply.

(2) Automated tack welding for assembly alignment is then performed by robots to guarantee component positioning accuracy.

(3) A dual-station robotic system carries out fully automated welding on both the front and back sides of the components. After manual grinding and repair to ensure surface quality, the components proceed to the automated unloading stage for final product separation.

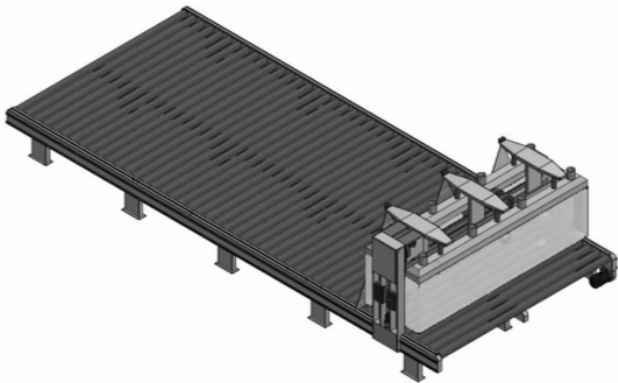


Fig. 4 Robotic Welding Station

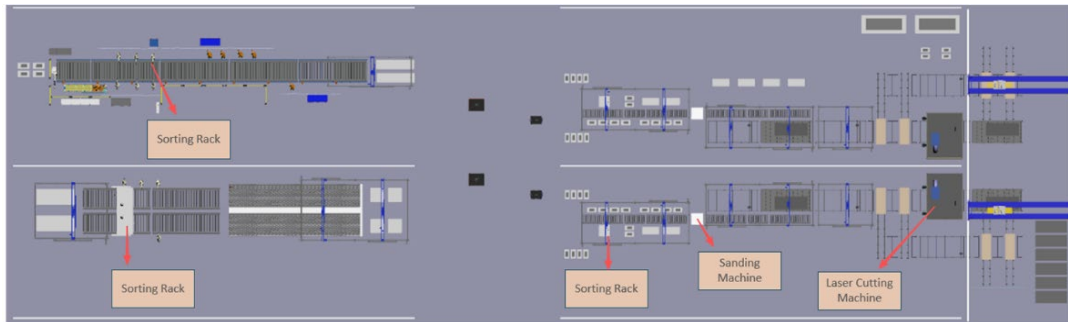


Fig. 5 Intelligent Workshop Model

### 5.1.2. Process Animation Design

In the system, each key process is designed using Unity's Timeline in combination with custom scripts to enable visual and interactive demonstration of the production workflow. The implementation is as follows:

(1) Process motion modeling: Based on the aforementioned process requirements, corresponding equipment motions and workpiece state changes were designed for processes such as steel plate feeding, laser cutting, sorting, AGV transportation,

(4) Material transfer is performed by AGV (Automated Guided Vehicle) systems, forming a complete intelligent production loop.

## 5. System Design and Implementation

The system realistically restores the workshop environment through 3D modeling, providing an intuitive display of the process workflow. Interactive operations are enabled via button controls, and the system also supports real-time display of key equipment information during production. This provides effective technical support for the digitalization and visualization of sub-assembly production.

### 5.1. Process Workflow Design

#### 5.1.1. Model Construction

The 3D model of the workshop production line was created using 3ds Max, as shown in Figure 5. During the modeling process, the model scope was first determined based on the actual workshop workflow and layout, including roller conveyors, robots, gantry cranes, workbenches, and auxiliary tooling. Geometric modeling was then completed using basic primitives along with operations such as Boolean, extrusion, and other modeling techniques. Repeated units were modeled in a modular manner to standardize components and improve efficiency.

The model was simplified and organized into layers to reduce redundancy. The ProOptimizer modifier was used to simplify high-polygon models by reducing polygons that have minimal impact on visual appearance, deleting invisible faces, merging adjacent planes, and optimizing geometry resulting from Boolean operations. Additionally, repeated or instanciable objects were duplicated using instancing to avoid unnecessary increases in polygon count.

and welding, ensuring that the animations closely match real operations.

(2) Timeline management: Timeline was used to control the motion of each process. By setting keyframes for equipment movement, rotation, and action changes, precise and continuous animations are achieved.

(3) Script-based event triggering: Animation Events were added at key points to display process information or indicate specific operations, enhancing the comprehensibility of the animations.

(4) Workflow integration: Process animations can be played independently or sequenced according to the workflow, forming a complete production demonstration. This allows users to flexibly observe either individual operations or the entire process.

### 5.1.3. Interactive Control and Implementation

To enable dynamic control of the process workflow by users, the system integrates Unity’s UI system with button event mechanisms for interactive design. The interface is shown in Figure 6, and the implementation details are as follows:

(1) Process selection control: A button list is provided in the interface, allowing users to click any process button to trigger the corresponding Timeline track animation.

(2) Process workflow playback: Buttons for key processes and the complete workflow are provided. By invoking Timeline sequences, the system demonstrates the production workflow from material feeding to welding.

(3) Animation control functions: Operations such as pause, fast-forward, and rewind are supported. This is achieved by dynamically controlling the Timeline’s Play, Pause, Stop, and time properties, allowing users to freely observe process details.

(4) Information and status feedback: During animation playback, process names, operational parameters, and key event prompts are displayed in real time, enabling users to understand not only the actions but also the critical points of the workflow.

(5) Interactive extensibility: The interaction logic is event-driven, facilitating future expansions such as equipment status simulation and process optimization guidance.

The system provides six interactive buttons. Taking the steel plate feeding process as an example, when the steel plate feeding button is clicked, the gantry crane moves to the storage area, and the steel plate is picked up by the magnetic module at the lower end and placed onto the transfer platform on the roller conveyor. Users can select either individual processes or the complete workflow via the interface, achieving autonomous control and dynamic demonstration of

the production process. This functionality effectively supports applications such as process training, production planning, and bottleneck analysis.

## 5.2. Process Information Visualization

To enable real-time monitoring of equipment status and process parameters, an industrial intelligent gateway was introduced in the system as a data relay and protocol conversion tool. Considering that real production equipment was not connected under the experimental conditions, this study utilized the virtual variable function of the Wutongbo Industrial Intelligent Gateway to construct simulated data, including key parameters such as “equipment operating hours” and “equipment temperature monitoring.” Through the gateway backend configuration, initial values and data types can be assigned to each virtual variable, and dynamic updates are achieved via the rule engine, ensuring continuous data output.

### 5.2.1. Data Simulation and Validation

In this study, to achieve real-time visualization of workshop equipment status, simulated data were generated using the Modbus Server in the HslCommunication testing tool and transmitted to the Wutongbo industrial gateway.

The specific procedure is as follows: the communication parameters in HslCommunication (IP address, port number, and protocol) were configured to match those of the gateway. Simulated data representing equipment operational states—including working hours, temperature, and switch status—were then generated and continuously transmitted to the gateway at predetermined intervals, as shown in Figure 6.

After receiving the data, device configuration and other settings were performed within the gateway, as shown in Figure 7. The uplink topic was then added to MQTT.fx through the gateway’s cloud service center to subscribe to the topics published by the gateway. This setup was used to debug and verify whether the gateway correctly transmitted the data to the MQTT server, as illustrated in Figure 8.

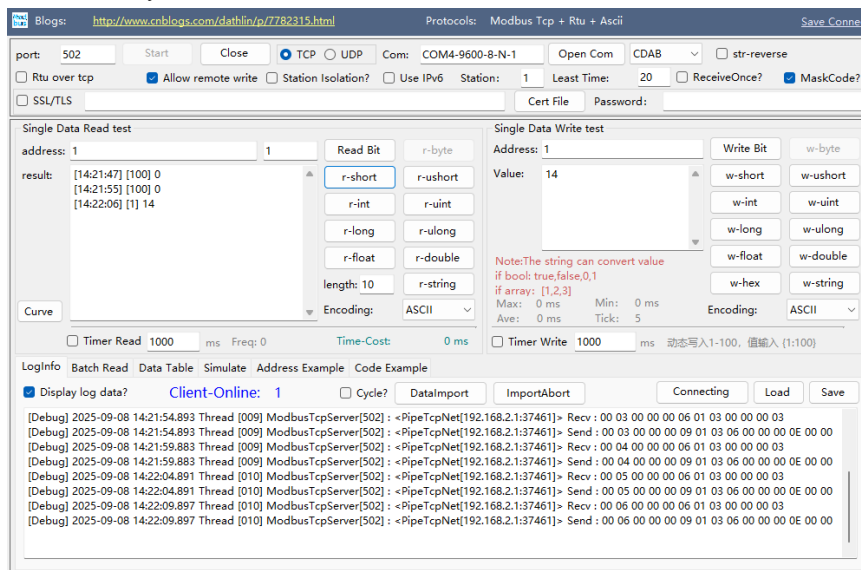


Fig. 6 Data Simulation

ID	Var Name	Variable	Data Type	Register	Operation
7	shichang	GZS	SHORT	4X0	<input type="button" value="Edit"/> <input type="button" value="Copy"/> <input type="button" value="Delete"/>
8	zhuangtai	gzzt	SHORT	4X2	<input type="button" value="Edit"/> <input type="button" value="Copy"/> <input type="button" value="Delete"/>

Fig. 7 Data Testing and Validation

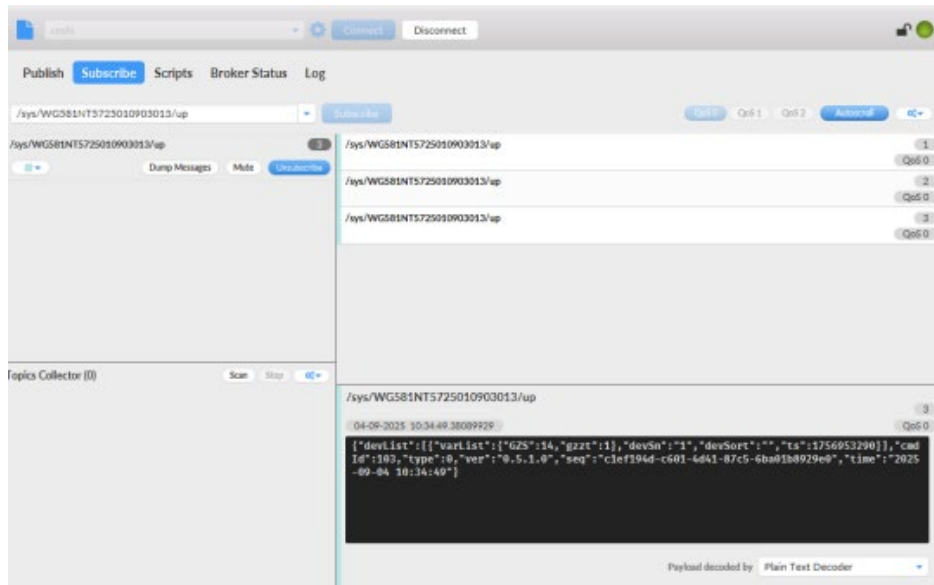


Fig. 8 Data Debugging

### 5.2.2. System Information Display

After completing data acquisition verification using MQTT.fx, it was confirmed that the MQTT Broker server was operating normally, which laid the foundation for subsequent data reception in Unity. To enable communication between Unity and MQTT, the MQTTnet.dll dynamic link library needs to be included in the project and placed in the Plugins folder.

In the C# environment, an intermediary program can be used to establish a connection between the database and the server. This program typically listens for MQTT messages and writes the received data into the database. Before use, the server address and port, topic, as well as the MySQL database username, password, and corresponding data tables need to

be configured. Figure 9 shows a partial code example of this intermediary program.

The system implements real-time status monitoring of key workshop equipment, as shown in Figure 10. Taking the laser cutting machine as an example, it can display the equipment's operational status, cumulative working hours, and key parameters such as temperature in real time. Currently, the laser cutting machine is in operation, with a cumulative working time of 18.3 hours and a temperature of 38 °C. This functionality provides an intuitive reflection of equipment conditions, offering valuable reference for production management, facilitating timely detection of anomalies, optimizing scheduling, and improving equipment utilization and production safety.

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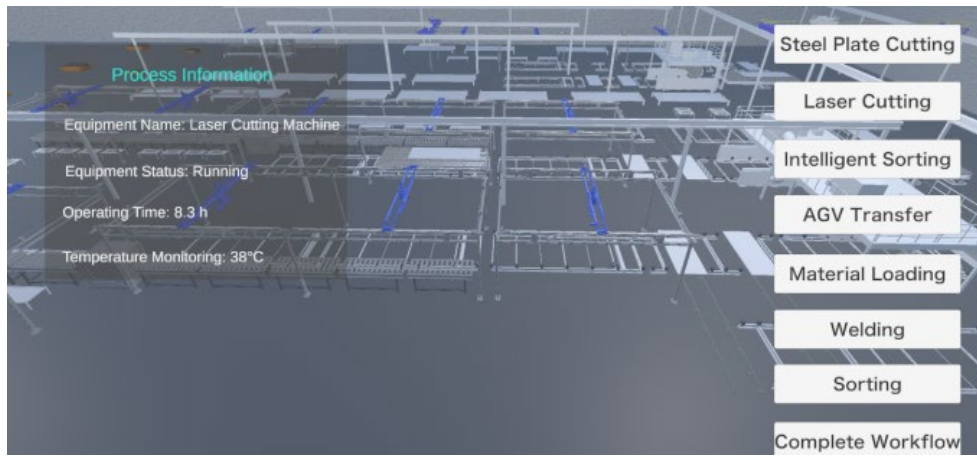
if (!string.IsNullOrEmpty(latestMessage))
{
    Root root = JsonUtility.FromJson<Root>(latestMessage);
    if (root.devList != null && root.devList.Length > 0)
    {
        int workTime = root.devList[0].varList.GZS;
        int workStatus = root.devList[0].varList.gzzt;

        string statusText = workStatus == 1 ? "Running" : "Stopped";

        dataText.text = $"Work Time: {workTime} h\nStatus: {statusText}";
    }
}

```

Fig. 9 Partial Code of the Connection Program



**Fig. 10** Real-Time Equipment Status Monitoring

## 6. Conclusion and Outlook

This study addresses the visualization and operational requirements of complex workflows in ship sub-assembly workshops by designing and implementing a Unity-based interactive process visualization system. The system reconstructs the workshop environment and key equipment through 3D modeling and integrates animation with interactive controls to enable dynamic demonstration and autonomous operation of critical processes, including steel plate feeding, laser cutting, intelligent sorting, AGV transportation, and robotic welding. The system enhances the intuitiveness and flexibility of process workflow visualization, while providing effective support for personnel training, production planning, and bottleneck analysis, thereby laying a technical foundation for the digital transformation of sub-assembly workshops.

Future work can be further expanded in the following directions: (1) integrating the system with workshop production data to establish a real-time digital twin environment; (2) enhancing process optimization and scheduling functionalities to improve resource utilization and operational efficiency; and (3) enriching the interactive experience, for example by incorporating virtual reality or augmented reality technologies to increase the immersion of training and operations. With these improvements, the system

is expected to offer broader application value in smart manufacturing and shipbuilding.

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