

Preliminary Report: Industrial Digital Twin Conceptual Design GAC Motors Facility

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General Information

- **Target Audience:** Digital Modeling Team and System Integrators (IT/OT).
 - **Main Objective:** Document the physical, informational, and functional architecture of the GAC facility to guide the construction of its **Digital Twin**.
 - **Modeled Facility:** [GAC Facility Name, e.g., Guangzhou Smart Factory - Aion Line]
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1 Physical Modeling (*The What and Where*)

This section provides the geometric and kinematic data required to create the 3D representation and simulate movements.

1.1 Facility Description and Architecture

- **CAD/GIS Data:** Provide 2D/3D blueprints (STEP/DWG format) for all four main shops (Stamping, Welding, Painting, Assembly).
- **Required Spatial Accuracy:** The model must have a spatial accuracy of less than 5 cm to ensure precise virtual sensor placement and collision simulation.
- **Modeling Priorities:**
 1. **Primary Flow:** Welding and Painting Lines (where the vehicle body is formed and treated).
 2. **Secondary Flow:** Final Assembly Line and testing areas (integration of intelligent systems).

1.2 Machinery Inventory and Kinematics

- **Static Machinery:** Provide CAD models and technical specifications for energy consumption. The instantaneous energy consumed (kW) is a critical attribute for simulating the operational cost and carbon footprint.
- **Dynamic Machinery:**

- **Robots/Cobots (KUKA/ABB):** For each robot, provide the exact model, number of axes, the range of motion for each joint, and the exact cycle time for each task (to the millisecond precision).
- **Conveyors / Transfer Systems:** Nominal speed (target 0.2 m s^{-1}), acceleration, and deceleration profiles.

[Image of an automated welding shop in an automotive factory with multiple robotic arms]

2 Informational Modeling and Data Flow (*The How and When*)

This section defines the real-time data sources that will feed the Digital Twin to keep it synchronous with reality.

2.1 Data Source Systems (IT/OT)

The Digital Twin must aggregate data from the following key systems:

Table 1: Data Source Matrix for the Digital Twin

| Source System | Primary Role | Required Data for Digital Twin | Target Frequency |
|------------------------------------------------------------------|------------------------------------------|-------------------------------------------------------------------------------------------------------|---------------------------|
| MES (<i>Manufacturing Execution System</i>) | Tracking Work Orders (WO) and Takt Time. | WO Status, VIN (Vehicle ID Number) at each checkpoint. | Real-time (status change) |
| SCADA / PLCs (<i>Programmable Logic Controllers</i>) | Machine control and supervision. | Machine Error Code, Pressure/Temperature of paint nozzles, Torque value (Assembly). | 1 Hz |
| ERP (<i>Enterprise Resource Planning</i>) | Inventory management. | Inventory Level of critical parts (e.g., batteries), Scheduled Delivery Date (SDD) for raw materials. | Event-based (stock entry) |
| Vision/QC Systems | Quality Control. | Non-Conformity Rate (NCR), Dimensional Deviations of the chassis. | End of QC cycle |

2.2 Communication Architecture

- **Exchange Protocol:** A lightweight industrial protocol (e.g., MQTT) for communication from machine to the local/cloud server hosting the Twin.
 - **Target Latency:** The maximum acceptable latency between the physical event and its representation in the Digital Twin must not exceed 300 ms.
 - **Data Volume:** Estimated data flow of **2000** Data Points Per Second (DPPS) across the four main workshops.
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3 Functional and Behavioral Modeling (*The Logic*)

This section defines the business rules and logic that govern interactions within the virtual factory.

3.1 Flow and Sequencing Rules (Lean Manufacturing)

- **Takt Time Adherence:** The Twin must be able to simulate the accumulation of WIP (*Work In Progress*) if a station exceeds its defined cycle time.
- **JIT/JIS Logic:** Model the pull signals for components (e.g., Just-in-Sequence delivery for dashboards, Just-in-Time for tires) through virtual signals generated by the Twin.
- **Failure Simulation:** Integrate historical MTBF (Mean Time Between Failures) and MTTR (Mean Time To Repair) data for critical equipment to evaluate the production schedule's robustness.

3.2 Modeling of Resources and Skills

- **Work Capacity:** Operators are modeled as resources with minimum cycle times based on the ergonomic and complexity level of the task.
- **Skill Matrix Rule:** The simulation must prevent the reassignment of a virtual operator (in case of absenteeism) to a position for which they lack the required certification (e.g., high-voltage system installation for the Aion electric models).

4 Digital Twin Objectives and Use Cases

The Digital Twin will serve as an experimentation platform and a decision-support tool.

Table 2: Target Use Cases for the GAC Digital Twin

| Use Case | Simulation Description | KPI Validated / Optimized |
|-----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|
| New Model Introduction Validation | Simulate the integration of a new Aion model (with unique assembly steps) on an existing line to identify potential bottlenecks. | Mixed Model Production Efficiency. |
| Energy Optimization | Simulate shutting down or reducing machine power during low demand periods, correlated with real-time energy prices. | Operational Cost and Carbon Footprint. |
| Quality Forecasting | Use real-time torque and metrology data to predict the probability of a defect on a specific vehicle before it reaches final quality control. | Predictive Defect Rate. |

5 Conclusion and Next Steps

This report structures the requirements for a faithful digital modeling of the GAC Motors facility. Validation of these specifications is mandatory before commencing the 3D modeling.

1. **Phase 1:** Validation and freezing of this Functional Requirements Specification (FRS).
2. **Phase 2 (Next Step):** Auditing and Standardizing the raw data formats from PLCs/SCADA to prepare for system integration.