World Models

General Introduction:
The following describes a scenario from the field of production. It involves an automated, modular production line.

Scenario 1 (used for several questions)

Scenario Description

This scenario details a fully automated production line designed for the refinement of automotive glass using polyurethane. It includes not just individual machines but an entire production line. This production line is divided into three manufacturing cells (1: Primer Cell and Component Delivery, 2: Foaming Cell, and 3: Trimming Cell and Component Dispatch), which have been integrated into the production process and are described below.

Cell 1: Primer Cell and Component Delivery
The Primer Cell covers all necessary steps required before the actual foaming process. To ensure optimal adhesion between the glass pane and the polyurethane, a primer containing UV components is used. The primer acts as an adhesion promoter, while the UV components are later utilized for quality control through a camera system.

The Primer Cell consists of the following modules: Glass rack for component delivery, centering station, primer mixer, primer station with camera system, robot including gripper system for handling components, and flash-off station.

Initially, the glass pane is manually cleaned and pre-conditioned in the glass rack. The primer is prepared in the primer mixer and then filled into the primer station. The glass panes enter the automatic process via the glass rack. Using the gripper system, the robot removes the glass pane, centers it at the centering station, and then transfers it to the primer station. Here, the primer is applied via an application head and immediately checked using the camera system. Following inspection, the primed glass pane is placed in the flash-off station, which serves both as a buffer storage and ensures the primer has sufficient time to flash off and react.

Cell 2: Foaming Cell
The developed Foaming Cell handles the actual foaming process. Here, the pretreated glass pane, necessary inserts, and polyurethane are combined. The mold carrier system, along with the foaming tool, is located within the foaming cabin, while the polyurethane machine is positioned outside the protective area. It connects via a piping system to the mixing head, which is attached to the foaming tool.

The Foaming Cell consists of the following modules: Foaming cabin, mold carrier system, foaming tool, handling robot for tool cleaning, mold release agent application, insert placement, and polyurethane machine including barrel stations for polyol and isocyanate.

After the flash-off period, the glass pane is removed from the flash-off station and placed into the foaming tool by the robotic gripper. The handling robot prepares the tool for the foaming process by cleaning, applying the mold release agent, and placing inserts. Simultaneously, the polyurethane machine conditions and tempers the individual polyol and isocyanate components. Once the foaming tool is closed and the required clamping force is achieved, the liquid polyurethane is injected into the cavity of the tool via the mixing head. After the reaction and curing time for the polyurethane, the robot removes the foamed glass pane from the foaming tool.

Cell 3: Trimming Cell and Component Dispatch
All subsequent processing steps following foaming are carried out in the developed Trimming Cell. Here, excess polyurethane is removed from the component. Subsequently, a quality inspection is performed, and components are sorted as either acceptable or defective.

The Trimming Cell consists of the following modules: Robot including gripper system for component handling, trimming station with profile sensor, glass rack for component dispatch (acceptable components), and storage area for defective components.

Initially, the robot removes the sprue from the component, previously separated by the sprue trimmer in the foaming tool. Then, the robot takes the foamed glass pane to the trimming station. There, excess polyurethane along the separation edge and in the so-called "flush area" is removed by trimming disks. After trimming, the component's quality is verified with a profile sensor. If needed, rework is performed. Finally, the component is either placed in the glass rack (acceptable components) or into the storage area (defective components) and removed from the automatic process.

Scenario 2 (used for several questions)

Scenario Description

This simulation represents a discrete production process. The simulated plant is divided into seven distinct modules: 1. Incoming Goods, 2. Material Inspection, 3. Material Sorting, 4. Material Storage, 5. Material Processing, 6. Material Packaging, and 7. Outgoing Goods.

The simulation generates rectangular products with various parameters such as weight, dimensions, color, etc.

Module 1: Incoming Goods
Materials arrive at this module, which consists of a portal robot (further details below).

Module 2: Material Inspection
In this module, materials are reoriented on the conveyor through two parallel processing paths, and an optical inspection of incoming materials is simulated. The module includes a conveyor (further details below) and a 6-axis robot (further details below).

Module 3: Material Sorting
Materials that do not meet specified parameters are sorted out in this module. It includes a conveyor (further details below) and a material inspection device.

Module 4: Material Storage
Subsequently, inspected materials are stored and retrieved by Autonomous Mobile Robots (AMRs). This module includes an AMR (further details below).

Module 5: Material Processing
In this module, AMRs transport materials to processing stations in a matrix production layout. The material is manipulated by a robot, altering properties according to simulation parameters, such as color. This module includes an AMR (further details below) and a 6-axis robot (further details below).

Module 6: Material Packaging
Processed materials are then transported via two parallel conveyors into the packaging module and subsequently routed to outgoing goods. This module includes a conveyor (further details below) and a 6-axis robot (further details below).

Module 7: Outgoing Goods
Goods or products are dispatched here for transport to customers or storage. This module consists of a portal robot (further details below).

Description of Machines/Devices Used in Modules:

A: Conveyor Machine
A.1 Components: Motor, light barrier, conveyor track
A.2 Adjustable/Readable Properties:
Motor:
• Max. Speed
• Acceleration
• Deceleration
• State (On/Off)
• Direction
Extended:
• Maximum Roller Torque
• Roller Damping
• Mass in kg
• Current I
• Electrical Power
• Light barrier resistances
A.3 Possible Failures:
Overall:
• Emergency Stop
• Roller defect
Motor:
• Motor defect
• Incorrect speed calibration (double deviation)
• Wear
Extended:
• Increased damping

• Faulty current measurement
• Load too heavy

B: Portal Robot
B.1 Components: Motors, motor controllers, motor encoders
B.2 Adjustable/Readable Properties:
Engines:
• MaximumForce
• Mass
• Max Speed
• Acceleration
• Deceleration
• State (On/Off)
• Direction
• Current I
• Power electrical
Motor controller/encoder:
• TargetPosition
• Position
•Speed
• Acceleration
• atTargetPosition
• isAccelerating
• isDecelerating
• atSpeed
• isForwards
• isReverse
• isMoving
B.3 Possible Failures:
Total:
• Emergency Stop
Motor:
• Motor Defect
• Speed incorrectly calibrated
• Wear
Extended:
• Increased damping
• Load too heavy

C: (Details missing in original description; assume similar to Portal Robot or Conveyor)
C.1 Components: Motors, motor controllers, motor encoders
C.2 Adjustable/Readable Properties:
Motors:
• Maximum Force
• Mass
• Max. Speed
• Acceleration
• Deceleration

- State (On/Off)
- Direction
- Current I
- Electrical Power

Motor Controller/Encoder:
- Target Position
- Position
- Speed
- Acceleration
- atTargetPosition
- isAccelerating
- isDecelerating
- atSpeed
- isForwards
- isReverse
- isMoving

C.3 Possible Failures:
Overall:
- Emergency Stop

Motor:
- Motor defect
- Incorrect speed calibration (double deviation)
- Wear

Extended:
- Increased damping
- Load too heavy

D: AMR
D.1 Components: Vehicle
D.2 Adjustable/Readable Properties:
- MinAngle
- MaxAngle
- CurrentAngle

D.3 Possible Failures:
- Emergency Stop
- Motor defect
- Incorrect speed

E: 6-Axis Robot
E.1 Components: Drives
E.2 Adjustable/Readable Properties:
- Max. Speed
- Acceleration
- Deceleration
- Current I or Power

E.3 Possible Failures:
- Calibration (e.g. numerical imprecisions)

Prompts for Causal Inference Ability:

Manual prompted questions:

- Scenario 1:
  - "A glass pane is foamed with the described system. However, at the final inspection stage a defective glass is identified due to irregular and in some places too thin foam. Using your understanding of the production process described above, infer and describe the most likely sequence of preceding events or state transitions across the cells that could have led to this defect. Clearly outline the causal relationships between these events and the resulting system fault."
- Scenario 2:
  - "The product was colored on the wrong side. Using your understanding of the production process described above, infer and describe the most likely sequence of preceding events or state transitions across the cells that could have led to this defect. Clearly outline the causal relationships between these events and the resulting system fault."

Automatically generated questions:

- Scenario 1:
  - "A defective automotive glass component was identified at the final inspection stage in Cell 3 due to poor adhesion of the polyurethane foam to the glass surface. Using your understanding of the production process described above, infer and describe the most likely sequence of preceding events or state transitions across the cells that could have led to this defect. Clearly outline the causal relationships between these events and the resulting system fault."
- Scenario 2:
  - "The 6-axis robot in Module 6 (Material Packaging) has stopped unexpectedly. Upon inspection, it is found that the robot experienced a calibration failure leading to numerical imprecision. Considering the described modular production line, describe the most likely causal chain of system states or events across previous modules (Modules 1–5) and their respective devices that could have led to this specific failure event in Module 6. Clearly outline how each event causally connects to the next, referencing relevant devices, their properties, and potential failure modes described earlier."

Prompts for State Transition Comprehension:

Manual prompted questions:

- Scenario 1:
  - "In the system described, a product is removed from the process between steps 2 and 3. Please describe the condition of this product and its properties. To what extent does it differ from the input product and which processing steps would still be missing for completion?"
- Scenario 2:
  - "A square product is fed into the system. The sides are numbered 1-6 like a dice. On delivery, the product is on side 1. Sides 1 and 2 are to be colored during processing. In module 2, the cube is turned so that it is on side 6. The cube then falls off one of the AMRs. An employee places it back on the AMR, but does not pay attention to the orientation, so that side 3 is now at the

bottom. What effect does this have on the end product? what properties does it have? and are these the properties that were originally intended to be achieved?"

Automatically generated questions:

- Scenario 1:
  - "Starting from the moment a glass pane is manually placed into the glass rack in Cell 1, clearly describe each significant intermediate state of the glass pane as it transitions through the Primer Cell, Foaming Cell, and Trimming Cell. Conclude with the final states in which the component may end up after the entire production process is complete. Be specific about the physical state, location, and condition of the pane at each step."
- Scenario 2:
  - "A rectangular product arrives at Module 1 (Incoming Goods) and moves through each subsequent module until it exits the production line at Module 7 (Outgoing Goods). Initially, the product is identified as needing color modification during processing in Module 5. Describe, step-by-step, how the product's state (including position, orientation, and color) evolves as it progresses through Modules 1 to 7. Specifically, detail the changes in properties and configurations that occur at each module, clearly referencing interactions with each device (Portal Robot, Conveyor, AMR, 6-Axis Robot) as defined in the scenario."

Prompts for Multi-Variable Dependency Resolution:

Manual prompted questions:

- Scenario 1:
  - "An employee who is responsible for increasing efficiency notices that more glass panes can be foamed if, when the machine is started, the flash-off station is not filled with the primed panes first and then cell 2 starts work, but instead cell 2 starts work as soon as cell 1 has primed the first pane. How does this increase efficiency?"
- Scenario 2:
  - "A new product is fed into the process. The weight of the product exceeds the maximum permissible load of the conveyor belt. How does this affect the process?"

Automatically generated questions:

- Scenario 1:
  - "Suppose the polyurethane machine in Cell 2 experiences an unexpected increase in the temperature of the polyol component during the foaming process. Given the production line scenario described above, predict how this single parameter change (increased polyol temperature) would likely affect other related variables, such as reaction rate, curing time, polyurethane adhesion quality, and ultimately, the final product quality. Clearly explain the dependencies between these variables and the constraints inherent to the described production system."
- Scenario 2:
  - "In Module 2 (Material Inspection), the conveyor's motor speed is increased significantly above its normal operating speed. Considering the

interdependent variables described for the conveyor system—including maximum roller torque, roller damping, mass of products, electrical current, and motor load—describe how this single adjustment in motor speed would affect each of these interrelated variables. Additionally, explain how these variable changes could impact subsequent modules (especially Modules 3 and 4) and their ability to perform their respective functions effectively."

Prompts for Modularity and System Integration Reasoning:

Manual prompted questions:

- Scenario 1:
  - "A new primer has been developed. This leads to a significantly stronger adhesion but has to flash-off twice as long. How does this affect the process?"
- Scenario 2:
  - "In module 2, the speed of the conveyor belt is doubled. what effects does this have on the process? By how much this increases the output of the entire system?"

Automatically generated questions:

- Scenario 1:
  - "A defective automotive glass component was identified at the final inspection stage in Cell 3 due to poor adhesion of the polyurethane foam to the glass surface. Using your understanding of the production process described above, infer and describe the most likely sequence of preceding events or state transitions across the cells that could have led to this defect. Clearly outline the causal relationships between these events and the resulting system fault."
- Scenario 2:
  - "Suppose the Autonomous Mobile Robots (AMRs) used in Modules 4 (Material Storage) and 5 (Material Processing) are replaced with a new AMR model. This new model has improved speed and acceleration but a lower maximum allowable payload and a narrower range of operational rotation angles. Given this substitution, infer and describe the potential implications on overall system-level behavior across the entire modular production line. Explicitly discuss how these changes might affect interactions among modules, especially considering the AMRs' tasks, module throughput, and the performance constraints imposed by other devices (e.g., conveyors, 6-axis robots, and portal robots)."

Prompts for Sequential Understanding:

Manual prompted questions:

- Scenario 1:
  - "In order to reduce personnel costs, it is decided to dispense with cleaning the glass before the first cell. What impact does this have on the process and the costs?"
- Scenario 2:
  - "The modules 5 and 6 are rearranged and their order is swapped. How does this influence the overall process?"

Automatically generated questions:

- Scenario 1:
  - "Consider the following partial sequence of operations performed on an automotive glass pane in the described production line:
    1. Manual cleaning and pre-conditioning of the glass pane.
    2. Robot gripping and centering the glass pane.
    3. Primer application at the primer station.
    4. (Missing Step)
    5. Polyurethane injection into the mold cavity.

    Given this partial action sequence and your understanding of the described scenario, identify the missing intermediate step required to achieve the correct target system state before polyurethane injection. Explain why this step is necessary and what would happen if this step were omitted."
- Scenario 2:
  - "A product is currently in Module 4 (Material Storage) and has successfully passed through Modules 1–3, meaning it has arrived, been inspected, and sorted without defects. The next intended final state of the product is to exit Module 7 (Outgoing Goods), fully processed and packaged. The following partial sequence of operations has occurred:
    1. Module 4 AMR retrieves and moves product to Module 5 (Material Processing).
    2. Module 5's 6-axis robot modifies the product's color according to specifications.
    3. (Missing Step)
    4. The product is placed onto the conveyor of Module 6 (Material Packaging).

    Identify and describe clearly what the missing step (3) must be, explaining why this step is crucial for the correct sequential flow of operations within the described modular production line. Additionally, highlight the potential system inconsistencies or failures that would result if this step were omitted."