

MODULE 9

Controls Integration and PLC Interface

Conveyor Solutions Engineering | Professional Training Program

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SECTION 1: INTRODUCTION

If you are reading this module and the data exchange requirements at each smart decision point in your system have not yet been defined, stop. Go back to the process flow diagram. The controls architecture cannot be specified without knowing what information needs to move between systems, at which points, and who is making the decisions. That conversation belongs in the earliest planning phases of the project, not here. By the time a system reaches Module 9 level detail, the data handshakes should already be locked in the flow diagram.

Controls integration in a warehouse conveyor system operates across multiple layers. At the bottom is the machine controls layer: the PLC, the sensors, the drives, and the physical equipment they govern. Above that sits middleware, the software that translates between the machine world and the business systems world. Above middleware sits the Warehouse Control System or Warehouse Execution System, which provides supervisory control of the machines and in the case of a WES, begins to handle order planning and batching. Above that is the Warehouse Management System, which converts ERP data and order streams into waves that are released to the floor. At the top is the ERP itself, the enterprise system where orders, inventory, and business logic originate.

A solutions engineer does not need to be an expert at every layer. But they must understand all of them well enough to have intelligent conversations with every stakeholder on a project, from the PLC programmer to the WMS administrator to the customer's IT director. More importantly, they must understand which layer owns which decision, because a controls problem that is misidentified as a machine problem, or a data problem that is misidentified as a controls problem, will be sent to the wrong team and will not get resolved.

This module teaches the controls topology, the machine-level behaviors most relevant to conveyor system design, the data exchange model that governs intelligent sort decisions, and the specific controls considerations that must be resolved during the flow diagram phase before detailed design begins.

SECTION 2: LEARNING OBJECTIVES

By the end of this module you will be able to:

- 1 Describe the five-layer controls topology of a warehouse automation system and explain the role of each layer from the PLC up to the ERP.
- 2 Distinguish between a WCS and a WES and explain what each layer adds beyond the one below it.
- 3 Explain the data exchange model at a smart decision point: what the three-part handshake is, why it is required, and what happens when any part of it fails.
- 4 Explain anti-gridlock control conceptually, describe the mechanical design conditions that make gridlock possible, and identify the induction rate governance principle that prevents it.
- 5 Describe the hospital lane, explain what conditions route product there, and explain how it fits into the overall exception handling architecture of a sortation system.
- 6 Identify the controls questions that must be answered during the flow diagram phase and explain why deferring them to detailed design creates downstream problems.
- 7 Explain how machine-level controls parameters from earlier modules, including VFD ramp rates, PLC delays at transfers, and merge lane switching timing, connect to the controls architecture specified in this module.

SECTION 3: PREREQUISITES

Required Prior Knowledge

Module 1: Warehouse Ecosystem and Customer Discovery. The process flow diagram and the customer discovery conversations from Module 1 are where the data exchange requirements and decision hierarchy should have been established. If they were not, that gap must be addressed before this module can be applied.

Module 5: System Design and Flow Layout. The layered flow diagram from Module 5 identifies every smart decision point in the system. Those points are the locations where controls integration questions are asked and answered. Know the flow diagram before specifying the controls architecture.

Module 6: Rate, Speed and Capacity Calculations. VFD ramp rates, belt speeds, and gap requirements from Module 6 are machine-level parameters that feed directly into the PLC specification. Have those numbers before this module is applied.

Module 8: Transfers, Merges and Sortation. PLC delay calculations, merge lane switching timing, and induction rate requirements from Module 8 are direct inputs to the machine controls layer described in this module.

SECTION 4: THE CONTROLS TOPOLOGY

Understanding the controls topology is the foundation of every controls conversation on a project. The five layers from the ground up are as follows.

THE FIVE-LAYER CONTROLS TOPOLOGY

Layer	Name	What It Does	Who Owns It
1 — Ground	Machine Controls (PLC)	Controls the physical equipment: conveyors, drives, sensors, print and apply, robotics. Executes the logic that moves product, stops it, diverts it, and detects faults.	Controls engineer / integrator
2 — Interface	Middleware	Translates between the PLC and the upper software layers. Receives data from the machine layer and formats it for consumption by the WCS or WMS. Receives routing decisions from upper layers and passes them back to the PLC.	Software integrator / controls team
3 — Supervisory	WCS / WES	Warehouse Control System: supervisory control of the machines, manages sort decisions, lane assignments, and system status. Warehouse Execution System: adds order planning, batching, and product movement logic on the order side.	WCS/WES vendor or integrator
4 — Management	WMS	Converts ERP data and customer orders into waves. Releases waves to the floor. Communicates wave status and inventory position down to the WES/WCS layer.	WMS vendor / customer IT
5 — Enterprise	ERP	The business system. Orders, online platforms, inventory at the enterprise level. Feeds the WMS with order data. Does not communicate directly with machine controls.	Customer IT / business systems

THE SOLUTIONS ENGINEER'S LAYER

A solutions engineer must understand all five layers conceptually. Their working knowledge is deepest at Layers 1 and 2, where the conveyor design connects directly to the machine controls and the data exchange interface.

The most important controls conversation the solutions engineer has with the customer is not about Layer 1. It is about the data exchange at Layer 2 and above. What information needs to move between systems, at which points, and who makes the routing decisions. That conversation shapes every machine-level design decision that follows.

When a controls problem arises on a project, the first diagnostic question is: which layer owns this problem? A problem misidentified as a machine controls issue that is actually a data exchange issue at the middleware layer will be sent to the wrong team. Identifying the correct layer is the first step to resolution.

SECTION 5: CORE CONTENT

5.1 The Controls Conversation That Must Happen Early

The controls conversation with the customer during the planning phase is not about PLCs, sensors, or machine logic. It is about data. At each smart decision point in the system, three questions must be answered before the physical layout can be finalized.

The Three Data Questions at Every Smart Decision Point

What information needs to be known at this point to make the correct decision? For example: a barcode, a weight, a destination code, an order status.

Where does that information come from? Is it embedded in the barcode and readable at the machine level, or does it require a lookup from a higher-level system through middleware?

Who makes the decision? Does the PLC make the routing decision autonomously based on local logic, or does it request a decision from the WCS or WMS and wait for a response?

These questions must be answered during the flow diagram phase, not during detailed design, because the answer changes the physical layout. A decision point that requires a WCS lookup needs a scan tunnel or identification system, a middleware connection, and decision latency limits that affect the gap requirement and belt speed upstream of the sort point. A decision point handled locally by the PLC requires none of those elements. Discovering late that a decision point requires a WCS lookup when the layout was designed for local PLC logic means redesigning the induction section, relocating the scan tunnel, and recalculating the gap. That is a weeks of rework problem that a two hour conversation during planning would have prevented

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The controls conversation with the customer does not focus around machine level controls. It focuses around data acquisition at each smart point in the system. What information needs to be exchanged between the system controlling the automation and the systems of the house. That is fundamentally where a solutions engineer wants to live: what information needs to be ascertained from who, at what location, so we can make the decisions in our automation.

The rest of the details are very important but typically not important during the beginning stages of the design. However, if the customer is talking about wanting to do inline weighing, a print and apply system, or intelligent diverting, we do want to talk about what the decision hierarchy looks like, what decisions are being made, and who is making them. But this should be figured out in the beginning planning phases with the flow diagram. By the time you get to detailed design, it is too late.

5.2 The Data Exchange Handshake

At any smart decision point where the routing destination cannot be determined from local PLC logic alone, a three-part data exchange handshake occurs between the machine controls layer and the upper systems.

THE THREE-PART DATA HANDSHAKE			
Step	Direction	What Happens	Failure Mode
1. Request	Machine → Upper system	PLC reads identification (barcode, RFID, weight) and sends it through middleware to the WCS or WMS with a request for routing instructions.	No-read: barcode unreadable, item goes to hospital lane. Timeout: no response received within required window, item diverted to hospital lane or held.
2. Response	Upper system → Machine	WCS or WMS looks up the item, determines the destination, and returns a routing instruction through middleware to the PLC. Example: barcode 123 goes to lane 5.	Wrong destination returned: item diverted incorrectly. Delayed response: item has traveled past the decision point before instructions arrive, sort missed.
3. Confirmation	Machine → Upper system	PLC executes the divert and sends a confirmation back to the WCS that the item was positively diverted to the assigned destination.	No confirmation sent: WCS does not know if item reached destination, inventory accuracy compromised. False confirmation: item jammed but system records successful divert.

The response time for steps 1 and 2 is a physical design constraint. The item is moving on the conveyor from the moment the barcode is read, and the routing instruction must reach the PLC before the item arrives at the divert point. The gap between the scan tunnel and the divert point, combined with the belt speed, defines the maximum allowable response time. If the WCS cannot respond within that window, the gap or the belt speed must be adjusted to give it more time. This is why the data exchange architecture must be understood during the flow diagram phase, when belt speeds and gaps are being established.

5.3 Machine Controls: What the PLC Is Managing

While the solutions engineer's primary controls conversation with the customer focuses on data exchange, they must understand the machine controls layer well enough to specify it correctly and recognize problems when they occur. The key machine-level behaviors in a conveyor system are as follows.

Encoder Tracking

On a sorter, each item's position is tracked continuously from the moment it enters the sorter to the moment it is diverted. An encoder measures belt travel in precise increments and the PLC uses that measurement to know exactly where each item is at any given moment. This is what allows the PLC to fire the divert mechanism at precisely the right time even though the item was scanned at a different location upstream. The encoder is the mechanism that closes the loop between the identification event and the divert event.

Jam Detection and Lane Full Conditions

The PLC monitors photoeyes throughout the system to detect jams and lane full conditions. A jam is detected when a photoeye that should clear within a defined time window remains blocked beyond that window. A lane full condition is detected when the photoeye at the entry of a sort destination lane remains blocked, indicating the lane cannot accept more product. Both conditions require a PLC response, for a jam, the typical response is stopping the relevant zone and alerting the operator.

Lane full conditions are particularly important at a sorter because they directly affect what the sorter can do with the product it is trying to divert. If the destination lane is full, the item cannot be diverted there. The PLC must either divert it to the hospital/Jackpot lane or send the product to recirculation, which can trigger an anti gridlock response depending on the system design.

Anti-Gridlock Control

Gridlock is a condition specific to sorters with recirculation. It occurs when the recirculation conveyor, and all destination lanes are simultaneously full, leaving no path for product to move. When gridlock occurs, the entire system stops. Product cannot be diverted, cannot recirculate, and cannot be cleared without manual intervention.

Anti-gridlock control prevents this condition by governing the rate at which product is inducted onto the sorter based on the sorter's ability to clear product through its destination lanes. The fundamental principle is that induction rate must be correlated to clearance rate. If destination lanes are filling and the recirculation loop is accumulating product, the induction of new product must be throttled or stopped before the system reaches a state where no path is available. The PLC monitors lane status and recirculation load continuously and adjusts the induction accordingly.

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The way the controls interact with incoming product on a sorter has to be directly correlated to the rate at which the sorter can get rid of product or divert product. If you are inducting faster than the sorter can clear, you will fill the loop, fill the lanes, and have nowhere for the product to go. That is gridlock. The controls must throttle induction based on what is happening downstream, not just run at maximum speed because product is available upstream.

Anti-gridlock is important to understand as it pertains to mechanical design. The physical layout must provide enough lane capacity and recirculation buffer that the controls have time to respond before the system reaches a gridlock state. If the mechanical design does not give the controls enough runway, no amount of PLC logic will prevent gridlock under heavy load conditions.

The Hospital Lane

The hospital lane is a dedicated sort destination for exceptions. It is the destination of last resort when the system cannot determine where else to send a product. Items are routed to the hospital lane under several conditions: the barcode was not readable, the WCS returned no valid destination, the item failed a weight check or other reject criteria, or in some cases the assigned destination lane was full and no alternative was available.

At the hospital lane there is typically an operator workstation. The operator at the hospital lane triages each item, determines the correct destination, and either walks the item manually to that destination or re-inducts it into the sorter if the system can now handle it. The hospital lane is not just a mechanical requirement. It is part of the exception handling architecture and its throughput capacity must be sized to handle the expected volume of exceptions without backing up into the sorter.

Conditions That Route Product to the Hospital Lane

No-read: barcode was not successfully read by the identification system.

Lost track: the sorter lost position tracking on the item after it was inducted.

No destination returned: the WCS lookup returned no valid routing instruction within the response time window.

Reject criteria: the item failed inline weighing, dimensioning, or other quality check.

Lane full with no alternative: assigned destination lane is full and no backup destination is configured.

Unknown item: the barcode was read but the item is not recognized in the WCS or WMS database.

SECTION 6: TIPS AND TRICKS

TIPS AND TRICKS | MICHAEL COLLINS

Have the data exchange conversation with the customer before you draw anything. At every smart decision point in the flow diagram, ask: what information do we need here, where does it come from, and who makes the decision. If you cannot answer all three questions for every decision point, the flow diagram is not complete.

When a customer mentions inline weighing, print and apply, or intelligent diverting, that is your signal to go deeper into the decision hierarchy immediately. Those applications require a defined data flow between the machine layer and the upper systems before the physical layout can be finalized. Do not defer that conversation.

The response time between scan and divert is a physical design constraint. Calculate the maximum allowable WCS response time for each sort point based on belt speed and the distance between the scan tunnel's transmit location, and the divert mechanism. Share that number with the controls team early. If the WCS cannot meet it, the gap or the speed must change.

Design the hospital lane for throughput, not just for existence. A hospital lane that is too small or too slow to handle the exception volume will back up into the sorter and create a secondary problem. Size it based on the expected no-read rate and reject criteria, not just as a placeholder at the end of the sorter.

Anti-gridlock is a mechanical design problem as much as a controls problem. The PLC can only throttle induction if there is enough physical buffer in the system to absorb the throttle response time. If the mechanical layout gives the controls no runway, gridlock will occur regardless of the PLC logic. Build the buffer into the layout, not just into the code.

SECTION 7: NOTES AND INSIGHTS

NOTES AND INSIGHTS

The three-part handshake between the machine layer and the WCS is a timing constraint that travels back through the mechanical design. A WCS that cannot respond within the required window forces either a longer scan-to-divert distance, a lower belt speed, or a larger gap. All three have cost and layout implications. This is why the controls architecture and the mechanical layout must be developed in parallel, not sequentially.

The encoder tracking principle on a sorter is the same position tracking principle used in any CNC or robotics application. The item is treated as a virtual object moving through a coordinate system. The PLC knows where it is at all times based on belt travel distance from the point of induction.

The machine-level parameters from earlier modules all end up as PLC setpoints. The VFD ramp rate from Module 7 is a PLC parameter. The PLC delay at a transfer from Module 8 is a PLC parameter. The merge lane switching timing from Module 8 is a PLC parameter. All of those values must be documented and handed to the controls team as part of the design package. They are not details to be worked out during commissioning.

SECTION 8: EXPERT CALLOUT

EXPERT CALLOUT

Placeholder for expert insight on a controls integration failure caused by deferred data exchange definition. Reviewer to share a specific example where the data handshake requirements were not established during the planning phase, what the consequence was during detailed design or commissioning, and what the correct process would have looked like.

[Reviewer Name, Title, Company]

SECTION 9: PITFALLS

- ! Deferring the data exchange conversation to detailed design. The three data questions at every smart decision point must be answered during the flow diagram phase. Discovering late that a decision point requires a WCS lookup when the layout was designed for local PLC logic requires redesigning the induction section, the scan tunnel position, and the gap calculation. That is a weeks-of-rework problem.
- ! Treating the WCS response time as a software problem only. The response time budget between scan and divert is a physical constraint determined by belt speed and scan-to-divert distance. If the WCS cannot respond within the required window, the mechanical layout must change. Both teams own this number.
- ! Designing the hospital lane as a placeholder rather than a throughput element. The hospital lane must be sized for the expected exception volume. A hospital lane that backs up into the sorter creates a secondary jam condition that stops the entire system.
- ! Relying on PLC anti-gridlock logic without providing enough physical buffer in the mechanical layout. The PLC can only respond as fast as the system allows. If the mechanical design provides no buffer between the induction gate and the sorter loop, the PLC has no runway to throttle induction before gridlock occurs. The buffer is a mechanical requirement, not a controls requirement.
- ! Failing to document machine-level PLC setpoints from earlier modules as part of the design package. VFD ramp rates, transfer PLC delays, and merge lane switching timing are all PLC parameters that must be specified and handed to the controls team. If they are not documented, they will be set to defaults at commissioning and the system will not perform as designed.

SECTION 10: FOREST THROUGH THE TREES

How Controls Integration Connects to Everything That Follows

Module 9 is where the conveyor system design becomes a connected system rather than a collection of mechanical components. The flow diagram from Module 5, the rate calculations from Module 6, the transition designs from Module 7, and the transfer and sortation designs from Module 8 all produce outputs that become inputs to the controls architecture. The VFD ramp rate, the PLC delay, the merge timing, the induction rate, the scan-to-divert distance, and the gap requirement are all numbers that originated in earlier modules and land here as PLC setpoints.

The controls topology introduced in this module also changes how the solutions engineer communicates on a project. Understanding that the WMS owns waves, the WCS owns sort decisions, middleware owns translation, and the PLC owns machine execution means the engineer can direct every controls question to the right team without confusion. That clarity saves time on every project it is applied to.

Module 10 moves to safety, guarding, and code compliance. The controls layer connects to safety in direct ways: e-stop logic, zone control, light curtain integration, and safety PLC architecture are all machine-level controls topics. The understanding of the PLC layer built in this module is the foundation for understanding how safety devices integrate into the system in Module 10.

SECTION 11: KEY TAKEAWAYS

KEY TAKEAWAYS | MODULE 9

The controls topology has five layers from the ground up: machine controls (PLC), middleware, WCS/WES, WMS, and ERP. Each layer owns specific decisions. Identifying the correct layer for any controls problem is the first step to resolving it.

The controls conversation with the customer is about data, not machines. At every smart decision point: what information is needed, where does it come from, and who makes the decision. Answer these three questions during the flow diagram phase, not during detailed design.

The data exchange handshake at a smart decision point has three parts: request from machine to upper system, response from upper system to machine, confirmation from machine back to upper system. All three parts must work reliably for the sort point to function correctly.

The WCS response time is a physical design constraint determined by belt speed and scan-to-divert distance. Both the controls team and the mechanical team own this number.

Anti-gridlock control governs induction rate based on the sorter's ability to clear product through its destination lanes. It is both a controls requirement and a mechanical design requirement. The physical layout must provide enough buffer for the controls to respond before gridlock occurs.

The hospital lane is a throughput element, not just a placeholder. Size it for the expected exception volume. A backed-up hospital lane stops the sorter.

All machine-level PLC setpoints from earlier modules must be documented and delivered to the controls team as part of the design package. They are not details for commissioning.

SECTION 12: MODULE ASSESSMENT

Knowledge Check

Q1

Draw the five-layer controls topology from memory, name each layer, and describe in one sentence what each layer does. Then identify which two layers a solutions engineer must understand most deeply and explain why.

Q2

A sortation system has a scan tunnel 15 feet upstream of the first divert point and runs at 150 FPM. Calculate the maximum allowable WCS response time in seconds for a routing decision to be returned before the item reaches the divert point. Then explain what the mechanical design options are if the WCS cannot meet that response time.

Q3

Describe the three conditions that together create a gridlock situation on a loop sorter. Then explain the anti-gridlock control principle and identify the mechanical design element that must be present for that control principle to work.

Planning Phase Exercise

Q1

You are in the initial planning conversation with a customer for a new fulfillment center. The flow diagram shows three smart decision points: an inline scale that rejects overweight packages, a scan tunnel that reads barcodes and routes packages to one of 12 sort destinations, and a print and apply station that prints shipping labels based on order data. For each of the three decision points, answer the three data questions: what information is needed, where does it come from, and who makes the decision. Then identify which of the three requires a WCS lookup and explain why the scan-to-divert distance for that point must be established before the belt speed is finalized. Assume that the divert mechanism take .25 seconds to actuate

END OF MODULE 9

Next: Module 10 | Safety, Guarding and Code Compliance

Before continuing, compile all machine-level PLC setpoints from Modules 6, 7, and 8 into a single controls specification document. That document is the deliverable from Modules 6 through 9 and the input to the safety design in Module 10.

Confirm that the data exchange requirements at every smart decision point in your flow diagram have been answered. If any remain open, resolve them before Module 10.

The e-stop logic and zone control architecture from Module 10 will build directly on the PLC layer described in this module. The machine controls understanding developed here is the foundation.

