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White Paper

# Streamlining Machine Connectivity with Enclosure-less I/O Systems

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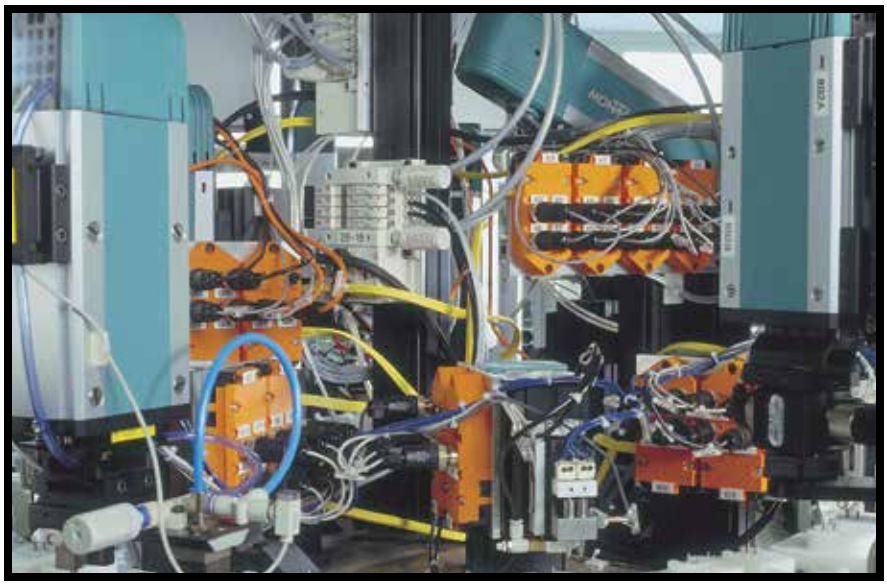
## Introduction

As manufacturing automation strategies embraced Design for Manufacturability (DFM), new automation technology advances and investments in industrial control systems for equipment, machinery and infrastructure led to distributed I/O, and, now, to enclosure-less I/O.

While quick disconnect connectors and enclosure-less I/O systems have been available for years, new industrial designs often still use enclosure-based strategies for I/O. These older, centralized enclosure come at a high price: the vast amount of cabling required to connect remote equipment to the terminations in the enclosure.

This paper explores the impacts connectivity and cabling have had on streamlining equipment and machinery, and the tradeoffs between enclosure-based systems and enclosure-less based I/O systems. It offers guidelines and application examples for use in determining when it makes sense to employ the streamlining capabilities of enclosure-less I/O.



## Enclosure vs. Enclosure-less

Enclosures provide a protected environment for cable terminations. Typically rated at IP20, they prevent personnel from injury as a result of injudiciously sticking fingers into the enclosure, while providing a fairly friendly environment that limits the amount of dirt and dust that can enter. Enclosures provided an effective solution to wiring needs when each cable required manual termination and connectors were not particularly robust. Downsides of enclosures are well-known—manual termination of all the wiring required for an effective plant design is time consuming and costly. In addition, the amount of wiring required to run every sensor signal from a machine to the central enclosure required complex wiring trough strategies (see Figure 1). The large numbers of cables radiating from the enclosure also made it hard to isolate faults when something went wrong, and, the time to replace a cable—cutting it, laying it out in the wiring tray and manually disconnecting the old cable and installing the new—when the fault was determined meant expensive downtime on the manufacturing floor.

The advent of quick disconnect connectors capable of operating in harsh environments opened a new world of flexibility and cost savings for industrial designers. The philosophy behind quick disconnect technology is that it provides cleaner, distributed wiring strategies that reduce the number of junction boxes and amount of cabling, and provides a measure of environmental responsibility by saving copper and the complexities of wiring troughs required using the enclosure-based system. Using connectors and cabling rated for harsh environments, I/O blocks can be mounted on or close to each machine rather than in a central area, and the overall amount of cabling required within an installation is significantly reduced. But the largest benefit comes from the reduced downtime required to replace a quick-release cordset when a fault occurs.

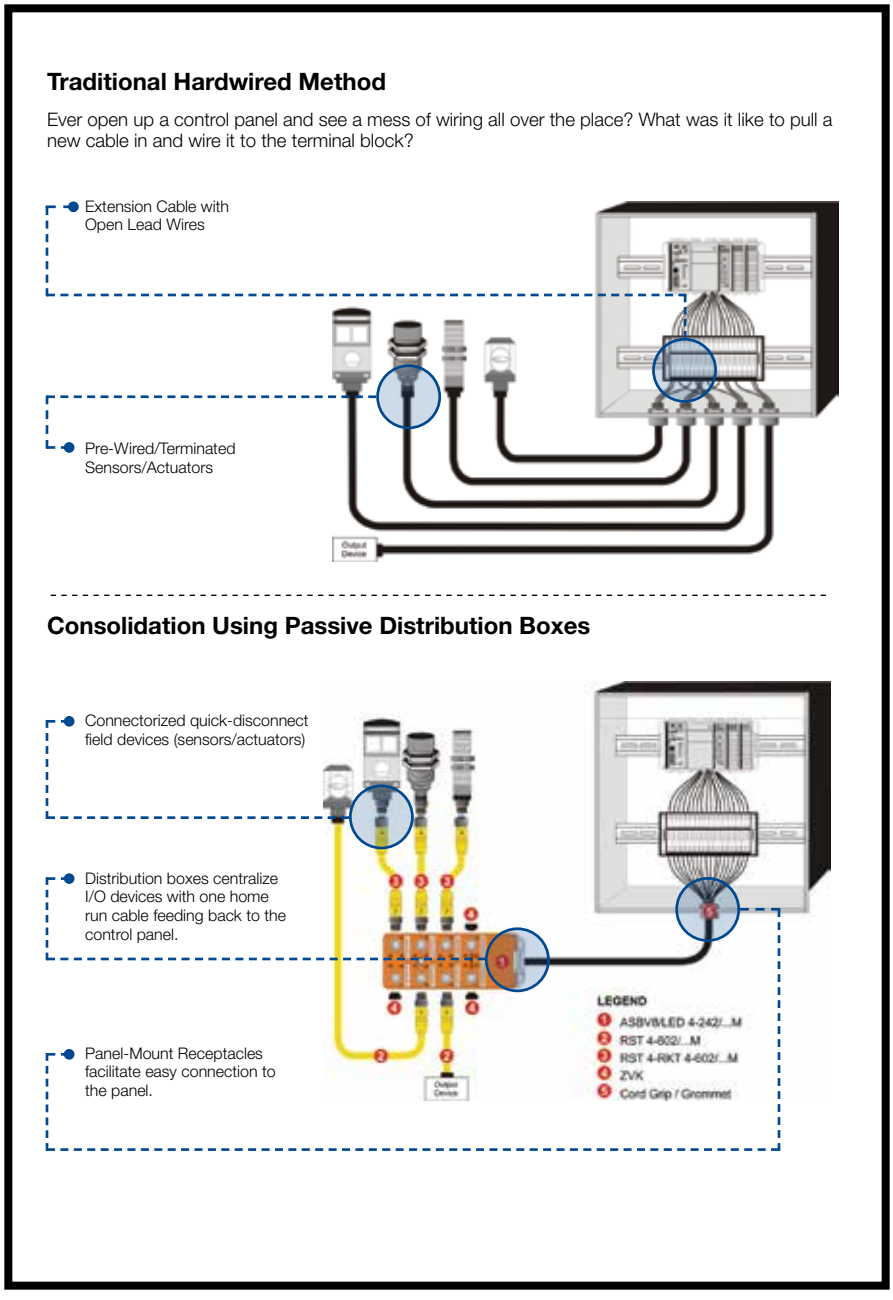



**Figure 1**: Enclosure-less I/O strategies provide multiple benefits including less cable to run initially and easier troubleshooting and faster fault resolution when alarms occur.

There are seven benefits of enclosure-less sytems that should be considered that are applicable to both OEMs and end users. It is particularly relevant for design specifiers who want to take advantage of the streamlined technology to provide lifetime savings in new products or installations.

### Simplifed Design

Design time is reduced because a significant amount of complexity is gone. A comparison of the two drawings in Figure 1 will drive this point home.

### Plug and Play Solutions

Because enclosure-less designs are easily modularized, it takes less time to design and put together complex systems. Design components can be mixed and matched to meet the requirements of the installation without having to create a new design each time. Using a simple cabling architecture to connect modules is much easier than redesigning a centralized cabling system each time, and the resulting modules cost less to build and deploy.

### Reduced Installation and Test Time

Modular systems are easier to install and debug because the complexity of the cabling system is dramatically reduced. Installation costs may be cut by as much as 30%. Because many modular systems use factory-terminated cabling, the liabilities of field-termination such as mis-wiring connectors or failing to properly close a connector are dramatically reduced—or they disappear. Another factor in reducing installation time is the reduced time necessary to debug faulty wiring—a notoriously difficult process in many enclosure-based designs.

### Reconfiguration

When a part of the process or manufacturing line needs to change, it is easy to add a new module. Reconfiguration of cabling from a centralized enclosure is eliminated.

### Reliability

With studies suggesting that system failures are more likely to occur because of faulty installation than from part failures, the advantages of factory-termined, factory-tested wiring are obvious. This makes enclosure-less sytems more reliable and increases productivity by reducing downtime.

Using a simple cabling architecture to connect modules is much easier than redesigning a centralized cabling system each time, and the resulting modules cost less to build and deploy.

### Reduced Time and Cost for Maintenance and Repair

Streamlined cabling means that Mean Time to Repair (MTTR) is significantly reduced. Problems are isolated more quickly, and replacement of failed parts or wiring can be handled locally without having to trace back to a complex panel, thus reducing both the time and cost of repair.

### Reduced Real Estate

Control cabinets and long wiring runs increase complexity—and take up real estate. Modular enclosure-less systems can often dramatically reduce the space requirements for cables and wiring panels, enabling manufacturers to use more of their floor space for production equipment.

## Enclosure-less ROI

The benefits of an enclosure-based system add up to faster ROI. As noted above, the cost of purchasing a streamlined enclosure-less solution may be somewhat higher than an enclosure-based solution. The initial cost is somewhat ameliorated by reduced installation costs—and the first time there is a failure in a cordset or a sensor most manufacturers find that the savings more than pay for front-end expense. Unfortunately, the initial cost differential is enough to discourage many contractors from building an enclosure-less solution into a bid unless it is specified in the RFP. When the contract is likely to go to the contractor with the lowest bid, it makes no sense for a contractor to include higher-cost items than are specified.

There are other hidden costs to an enclosure-based system. In an enclosure based system, the I/O modules (typically remote PLC I/O) are wired to terminal blocks in the panel, which then must be field-wired to the sensors and actuators during startup. It is possible that terminals may become loose inside the

## The True Cost of Downtime

Downtime is the nemesis of any industrial operation, and losses typically go far beyond the obvious. Losses due to downtime result in unrecoverable hits to profitability, as demonstrated by Figure 2.

It is easy to see that labor costs are involved on the line, but there are also indirect labor costs as managers and repair technicians become involved, and product costs from shutting down and starting up a portion of a manufacturing line, which also creates bottlenecks for production in other parts of the plant as full-capacity is no longer possible. When continuous flow systems fail, product in process must often be scrapped. In addition, product not produced during downtime when a factory or plant is running at or near capacity cannot be recovered.

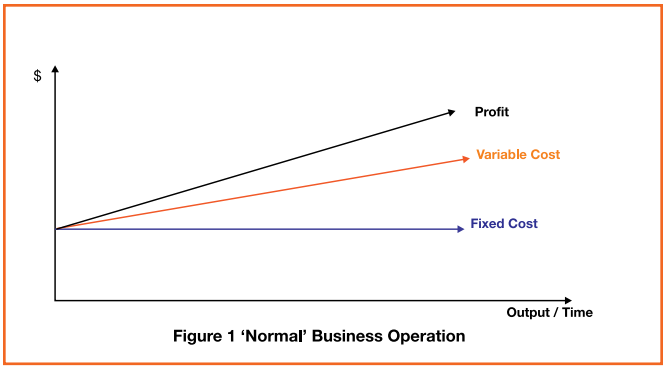



Figure 1 'Normal' Business Operation

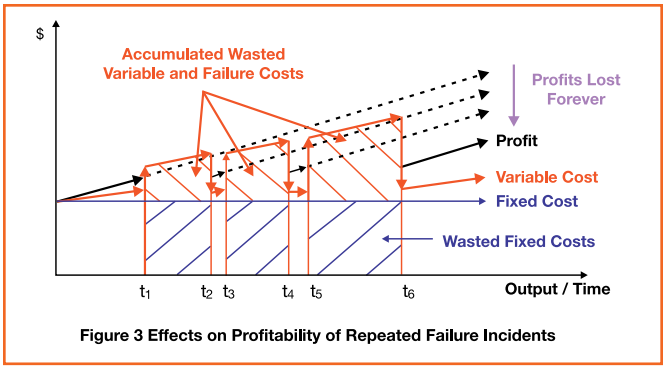



Figure 3 Effects on Profitability of Repeated Failure Incidents

**Figure 2**: Each downtime incident in a factory has an unrecoverable impact on overall profitability (diagrams courtesy of Mike Sondalini, author, *Defect and Failure True Cost*).

panel, during shipping, which means that to ensure successful installation; the terminals must be subjected to close inspection and retorquing of the screws during installation startup. In addition, the field wiring to the individual sensors and actuators may not be done perfectly. Either of these situations will create a delay as technicians take time to troubleshoot the problem. A streamlined solution, using on-machine I/O is faster to install because of its fully connectorized solution.

It is incumbent upon managers of plants and other industrial facilities to educate themselves and their purchasing departments on the relative benefits of enclosure-less solutions in various parts of their operation and specifically request them in the bids to keep the playing field even for contractors.

When determining the ROI of an enclosure-less system, operational costs take precedence over purchase price. In addition to time saved during installation, they also make a difference when an assembly line goes down. Assume that downtime in an industrial environment runs $1000 per minute in high-speed machine/conveyor operations (in some industries it can run much higher). In a streamlined enclosure-less system where short cordsets terminated by quick disconnect connectors can be quickly replaced—or when sensors fail, can be quickly attached to a replacement sensor—a repair crew can have the system working again in minutes. If it takes the crew 30 minutes to rewire the device back to a terminal block, your operation has lost $30,000. Streamlining pays for itself the first time the plant suffers downtime.

## Industrial Strength

Connectors rated IP20 are acceptable for any fairly benign environment. These are the types of connectors typically used within a standard NEMA 1 or NEMA 12 indoor enclosure, which protects personnel against access to hazardous parts, and also provides a degree of protection for the equipment against dirt, dust, link, fibers, filings and similar objects. NEMA 12 adds some protection against drips or light splashes of liquids. In order for enclosure-less I/O blocks to be used, connectors needed to be able to withstand harsher conditions; connectors with IP67 and IP69K ratings, enable suitably rated wiring to be deployed in less-protected environments.

IP67-rated housings are able to withstand liquids, dust and vibration. Thus IP67 connectors and I/O modules can be used on the factory floor in applications such as material handling and automated assembly, and are made of materials such as nickel-plated brass.

The IP69K rating provides additional protection for high-pressure, high-temperature wash-down applications in indoor or outdoor conditions. The IP69K test specification was initially designed for road

## Understanding IP and NEMA Ratings

The IP (Ingress Protection) Rating system is a worldwide standard for rating enclosures. It is designed to identify the level of protection that enclosures and equipment provide against incursion by human body parts (typically fingers or hands), particulates, moisture and corrosives. To interpret the rating (IP-"XY"), look up "X" in first table and "y" in the second table below.

The NEMA (National Electrical Manufacturers Association) rating system is primarily used in North America. NEMA standards roughly parallel IP ratings. For example a NEMA 1 rating is for general purpose enclosures and meets or exceeds an IP10 rating, while a NEMA 12 rating meets or exceeds an IP52 rating.

**Protection Against Solid Foreign Objects Penetrating the Product.**

| IP | 6 | 7 |
|---|---|---|
| Ingress Protection | First Index Figure<br>Protection Against Foreign Objects | Second Index Figure<br>**Protection Against Water** |

| 1st Index Number | Icon | Brief Description | Definition |
|---|---|---|---|
| 0 |  | No protection | Not applicable |
| 1 |  | Protected against solid foreign objects of 50 mm Ø and > | The object probe, sphere of 50 mm Ø, shall not fully penetrate** |
| 2 |  | Protected against solid foreign objects of 12.5 mm Ø and > | The object probe, sphere of 12.5 mm Ø, shall not fully penetrate** |
| 3 |  | Protected against solid foreign objects of 2.5 mm Ø and > | The object probe, sphere of 2.5 mm Ø, shall not fully penetrate** |
| 4 |  | Protected against solid foreign objects of 1.0 mm Ø and > | The object probe, sphere of 1.0 mm Ø, shall not fully penetrate** |
| 5 |  | Dust protected | Ingress of dust is not totally prevented, but dust shall not penetrate in a quantity to interfere with satisfactory operation of the apparatus or to impair safety. |
| 6 |  | Dust tight | No ingress of dust |

**NOTE**: To download a printable copy of the Ingress Protection Ratings, please go to **http://www.lumberg-automationusa.com/catalogs/icos/LA_Ingress_Protection_Ratings.pdf**

**Protection Class - Protection Against Ingress of Water with Adverse Effects.**

| IP | 6 | 7 |
|---|---|---|
| Ingress Protection | First Index Figure<br>Protection Against Foreign Objects | Second Index Figure<br>**Protection Against Water** |

| 1st Index Number | Icon | Brief Description | Definition |
|---|---|---|---|
| 0 | | No protection. | Not applicable. |
| 1 |  | Protected against vertically falling water drops. | Vertically falling drops shall have no harmful effects. |
| 2 |  | Protected against vertically falling water drops when the enclosure is tilted up 15°. | Vertically falling drops shall have no harmful effects when the enclosure is tilted at an angle up to 15° on either side of the vertical. |
| 3 |  | Protected against spraying water. | Water sprayed at an angle up to 60° on either side of the vertical shall have no harmful effects. |
| 4 |  | Protected against splashing water. | Water splashed against the enclosure from any direction shall have no harmful effect. |
| 5 |  | Protected against water jets. | Water projected in jets against the enclosure from any direction shall have no harmful effects. |
| 6 |  | Protected against powerful water jets | Water projected in powerful jets against the enclosure shall have no harmful effects. |
| 7 |  | Protected against the effects of temporary immersion in water. | Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is temporarily immersed in water under standardized conditions of pressure and time. |
| 8 |  | Protected against the effects of continuous immersion in water. | Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is continuously immersed in water under the conditions which shall be agreed between the manufacturer and user, but which are more severe than for numeral 7, above. |
| 9K |  | Protected against water from high-pressure / steam jet cleaners. | Water directed against the enclosure from any direction under extemely high pressure and must have no adverse effects. |

vehicles such as dump trucks and cement mixers that required regular intense cleaning, however, the same protection level makes IP69K-rated systems viable for applications such as food and beverage processing and even car washes. Not only are they dust-tight, but they must be water-tight under high-pressure and be able to withstand the application of steam. Another characteristic of IP69K-rated connectors is the need to withstand strong chemicals. IP69K-rated connectors are made with stainless steel to withstand pitting and cold as well as hot temperatures.

## What Constitutes an Enclosure-less Deployment?

Enclosure-less designs are not difficult to implement, however, the objective is to create a highly reliable end-to-end solution. Connectors, cables, cordsets, distribution blocks and receptacles must all conform to the same IP rating. Connectors have been discussed in detail above. The cable that is used between connectors must also conform to the standards set by the environments in which they are installed. Industrial environments, for example, require IP67- or IP69K-rated cabling that is designed for use in factory and process areas in unprotected and outdoor environments. Cables in these environments must be resistant to ingress of contaminants such as dust, moisture, water, oil and chemicals. Unsealed cables, rated at IP20, are suitable for protected enclosures and control rooms, although they may be subjected to harsh conditions such as extreme temperatures, EMI/RFI and vibration.

While some solutions may require field attachment of connectors to cables, many applications can take advantage of standard cordsets where standard lengths of cord are factory-attached to the required connectors. Cordsets further reduce the labor overhead of implementing enclosure-less designs, and also provide for the fastest repair when a cable or connector breaks down. It takes

only seconds to insert a cable between two quick disconnect connectors. Distribution boxes distribute power and signal for devices such as sensors, actuators, or dual-acting solenoids, and splitters can be used to bring two different sensor/actuator signals into a single port of a distribution box, thereby doubling the capacity of the box; Panel-mount receptacles mount in a fixed location (e.g., a sensor or panel enclosure) and mate with a molded or field-attachable connector, which is used to complete the assembly of a single-ended cordset.

## Applications

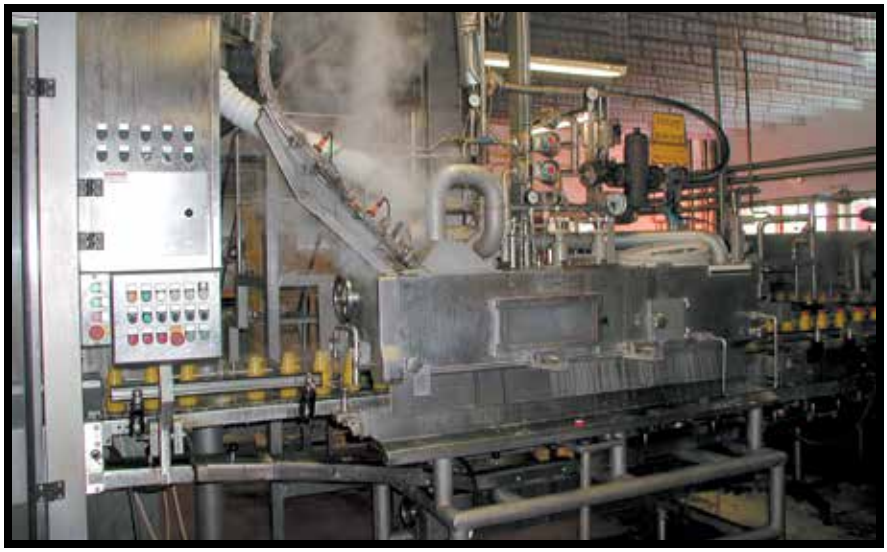
Enclosure-less designs work well in multiple industries to simplify installation and reduce downtime. It is important to note that enclosure-less designs, sometimes called machine-mount or on-machine automation, have value for machine builders as well as the factory floor (see References, "Modular IO Cuts Wiring Time 20%").

The following applications demonstrate the universal applicability of enclosure-less solutions in factory and plant environments.

### Food and Beverage

If a cabling system component or Ethernet switch fails in a food or beverage processing facility, the repair or labor costs alone could be 15-20 times the cost of the component itself and, depending on the circumstances, some consumables may even need to be scrapped. Downtime in the food and beverage industry can reach an astounding 500 hours annually. Unfortunately, in this industry certain factors encourage system failure and downtime.

The food and beverage industry has stringent requirements for product cleanliness, yet complying with the high levels of product hygiene mandated by the FDA means connectivity solutions are often subjected to environmental extremes such as the extreme temperatures and humidity associated with high pressure jet-spray wash-downs, sterilization, and exposure to caustic compounds, antibacterial cleansing solutions, disinfectants, organic acids, cooking fats, and other aggressive chemicals. Baking areas produce elevated temperatures. The processes themselves introduce shock and abrasion. It is important to protect the communication amongst PLCs, variable frequency drives, instrumentation, thermocouples, motors, pumps, ovens, conveyors and other components of a food and beverage processing line to ensure that tight tolerances and quality are maintained; controls for mission critical functions such as pasteurization, cleaning, cooling and refrigeration systems must work reliably or product may be compromised.



By using IP69K-rated I/O blocks and cabling, wiring layouts are simplified, and repairs can be made quickly using off-the-shelf double-ended cordsets in most instances. It goes without saying that only components that are designed, manufactured and tested specifically for harsh environments and mission critical operations should be installed.

### Material Handling

Today many distributors and large retailers operate giant warehouses stocking thousands—or 10s of thousands of SKUs. Given the lengths of some of the conveyor lines and the number of sensors and actuators employed, running large numbers of cables back to a central enclosure is neither efficient nor cost-effective. I/O blocks and cabling that is IP67-rated work well in most warehouse settings, although it behooves the designer to check out all conditions before creating specifications.

The material handling application sorts products and prepares shipments using long conveyor line system. For example, a distribution warehouse for a large discount chain serves 50 stores and is laid out so that each store has a chute. As the product is picked and makes its way down the conveyor line, sensors need to recognize the

SKU and also sense when it is approaching the appropriate chute in order to alert the appropriate actuator to push only the ordered material off the conveyor line.

Other applications requiring sensors and actuators within a warehouse include sensing when a section of the conveyor line is not being used in order to conserve energy. Conveyor lines are made up of 20-ft. conveyor belts, each with its own motor. When a sensor detects that nothing is on the belt, it can turn the section off until packages approach that section, and then turn it on when product is sensed to be approaching the conveyor belt in question.

**Water & Wastewater**

In water and wastewater treatment plants, connectivity solutions must endure high levels of humidity, grit, sludge and, in some cases, corrosive gases such as hydrogen sulfide and chlorine. Like most other public (and private) organizations, water and wastewater facilities are under pressure to increase operational efficiency and cut costs. Automation is necessary to keep these facilities running cost-effectively, and reliable operation is imperative. Measuring instruments such as thermocouples, strain gauges, load cells and flow meters must reliably send signals to PLCs. PLCs must continuously and dependably monitor and control critical process parameters such as tank fill levels, water flow rates, water temperature, oxygen level, and pH.

Municipalities and other water and wastewater management operations often have more than one plant site, as well as remote pumping stations that need to be linked into the information system. The remote pumping stations are frequently unstaffed and housed in underground concrete enclosures that are subject to temperature extremes, thus, industrial-strength connectors and cables are mandatory for proper functioning.

Modern water treatment plants typically depend on computer-controlled devices and remote monitoring over fast and reliable networks to support the collection of data from numerous locations within several plants and make that data accessible to any device or person on the network that requires it. While many water facilities have legacy enclosure systems in place, they can benefit from implementing enclosure-less designs as they build out facilities or replace aging infrastructure. Water treatment facilities will typically require a range if Ingress Protection ratings (IP67 to IP69K) for different parts of the facilities, and given the distances involved, enclosure-less solutions are often the best deployments.

**Transportation**

Sensors and actuators are deployed over long distances to keep trains running smoothly and safely. Tracks are divided into sections and managed by a series of signaling devices that alert remote control rooms as trains pass through their zones. The signals from sensors along the tracks allow controllers to move tracks and set signal lights appropriately for train engineers. Enclosure-less solutions using IP67-grade components can be set up to monitor and control segments of the track, using one of the ports to send signals wirelessly back to the appropriate control room. This saves significant cabling, not just to and from the sensors and actuators, but also by eliminating a long fiber optic cable run along the tracks.

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## Summary

Industrial automation is at the heart of the modern world's ability to manage the large and complex facilities and infrastructure that are hallmarks of our society. As interdependencies grow, the systems' tolerance for downtime decreases dramatically. Streamlining the cabling system in all applications ranging from food processing to warehouse distribution to municipal facilities and transportation makes good design and economic sense. Minimizing downtime through a cabling strategy that supports rapid detection and repair of cable and sensor failures means significantly less waste and significantly higher uptime. It is incumbent upon industrial system specifiers to ensure that RFPs are written with an awareness of lifetime costs of ownership, as well as initial purchase price and deployment costs in order to ensure that their facilities are built out with the most effective technologies.

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