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# Ethernet for Machines and Robots

Upgrading to Ethernet-based networks improves machine and robot performance, uptime and connectivity.

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## Table of Conents



## Executive Summary

OEMs are increasingly using industrial networks to connect their HMIs, controllers, distributed I/O, instruments and sensors to each other within a machine or a robot; to connect to their customer's control and communication systems, and to connect back to their home offices from their customer's site.

The ubiquity of Ethernet is improving its knowledge base and its price/performance ratio over other networks, and these and other advantages will eventually make many other networks uncompetitive. As a consequence, Ethernet is quickly becoming the network of choice for robot and machine builder OEMs and for their customers. In addition, automation components suppliers are including Ethernet and IP connectivity on more and more of their devices, creating a virtuous and ever expanding circle of Ethernet use.

Demand from OEMs and their customers for increased connectivity is driving Ethernet's increased use in the industrial arena, with growth forecast at approximately 10% per year through the next five years.

Some limitations remain when applying Ethernet with low cost sensors, so other low level networks will continue to exist for the foreseeable future. But as Ethernet advances technically, it's overcoming these limitations, particularly in terms of power delivery to sensors via the network and daisy chain connectivity.

Ethernet is the network of choice for many machine and robot builder OEMs and its use will continue to grow as prices decrease, as performance increases, and as features are added. For most OEMs, it makes sense to evaluate Ethernet as a solution to their network needs.

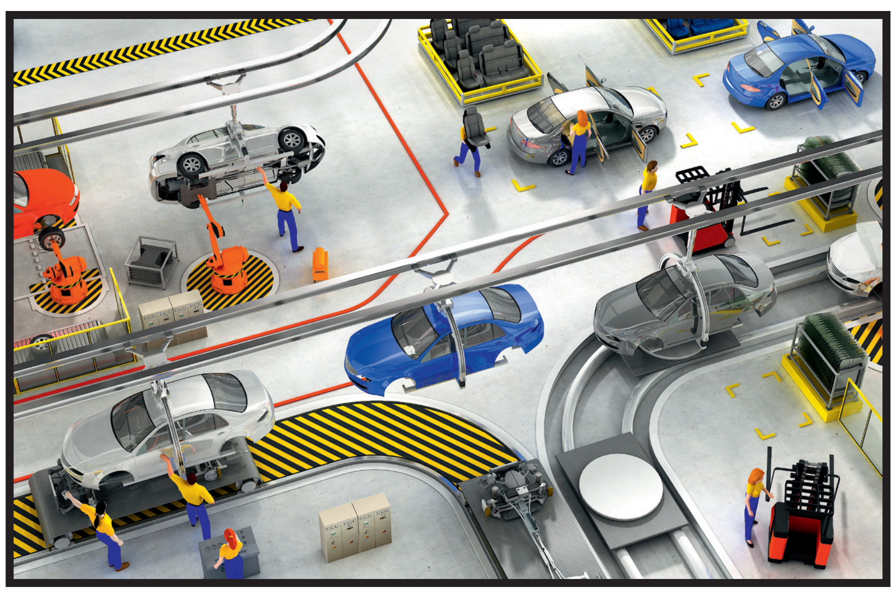

**Figure 1**: Illustration depicting an automotive body and assembly plant with integrated conveyor and robotic applications.

## Why Ethernet?

Ethernet is being used in such a wide range of applications that one could say it's reached the point where part of the reason it's so widely used is because everyone is using it. Of course, if there were no benefit to using Ethernet as compared to one of the other available options such as serial based communications, this trend wouldn't be so powerful.

In the commercial and office environment, computer and device serial ports are being replaced by Ethernet ports with IP addresses. Much the same trend is evident in the industrial arena as PCs, controllers, I/O, motor drives, instruments, sensors and other automation components increasingly include one or more Ethernet ports.

As depicted in Figure 2, IP addresses reside at Layer 3 of the OSI model. Though Ethernet is officially defined by Layers 1 and 2 of the OSI model, in reality most people use the term Ethernet to encompass Layers 1 through 4 thus including IP as well as TCP/UDP, and that's the terminology that will be used throughout this document.

The beauty of the OSI model is that it enables the top layers 5 through 7, the space where all the protocols and network management components of a network reside, to be reused when upgrading from a serial network to Ethernet. As a result, it's possible to quickly migrate from a serial-based protocol such as Modbus to an Ethernet-based protocol like Modbus TCP with minimal effort, and most importantly with little or no change to the end user in terms of required support and training.

Specifically, if Modbus was being used for networking over a serial link, most of the communication code and program would continue to be valid in the new Modbus TCP Ethernet environment. The main difference would be the capability to transfer data at much higher speeds. Other benefits would include wider availability of newer automation components with an Ethernet port as opposed to a Modbus port, along with increased ease of integrating these new components into the overall control and communications network.

The basis for this easy integration is the widely used and accepted standards at all layers of the OSI model. These standards support and make possible the integration of components from multiple suppliers in a common environment, effectively making it possible to plug and play with little or no effort required to create custom software communications code.

Even the simplest of today's production lines include a wide range of different machines and robots, most often supplied by a number of OEMs. Adding to the complexity is the fact that most machines and robots contain a number of automation components such as HMIs, controllers, motor drives, instruments and sensors.

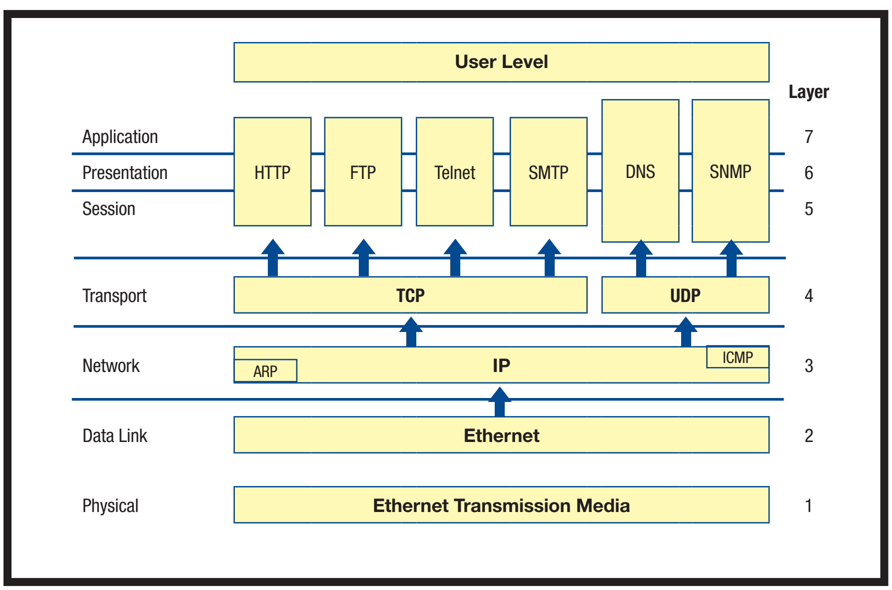


**Figure 2**: TCP/IP and OSI Model

All of these components need to communicate not only with each other within a machine or robot, but often with other machines and robots to closely coordinate and optimize production. Two-way communication is also required among machines, robots, and customer control and communication systems. Fortunately, many Ethernet-friendly standards and protocols exist to simplify these communications including ISA-88/PackML (batch and control), ISA-95 (data integration), and ISA-99 (security).

Implementing industry standards and protocols to integrate the real-time control network with the business network is made easier when the underlying infrastructure for both systems is the same. This further promotes the use of Ethernet on the plant floor as that network reigns supreme in the office and commercial world.

## Obstacles & Objections

The case for Ethernet in machines and robots appears strong, but many have negative preconceptions based on past experiences that are no longer relevant, primarily in the following areas:

- Speed & Determinism: In the 90's, there was much discussion about Ethernet's determinism or lack thereof. Today, with the majority of buses having an associated Ethernet protocol (e.g. EtherNet/IP, ProfiNet, SERCOS III) making the necessary augmentations to Ethernet, this argument is largely moot. Further mitigating this concern is the fact that Ethernet typically has orders of magnitude bandwidth versus the conventional bus, and that Ethernet equipment is typically installed full duplex with switches to avoid collisions. The bottom line is that performance is no longer an issue in the vast majority of applications, and solutions are available when greater speed and determinism are required (see Sidebar: Ethernet Protocols).
- Cost: With the increase in the number of vendors offering Ethernet based products and the resulting competition, along with Moore's Law, prices for Ethernet hardware continue to decline. In fact, many automation components such as industrial PCs and PLCs have Ethernet built-in, so it's now less expensive to use Ethernet than any other industrial network.
- Product Availability: Today, there are several choices of suppliers in each product category, providing standard unmodified Ethernet is used. One need only look at the product web page featured on each of the protocol web sites to view available options. If gateways are used, options increase many fold.
- Topology: The widely used Ethernet star configuration with each device connected to a switch port poses problems for some types of machine and robot automation system architectures. Suppliers are addressing this issue by embedding 2-port switches into their automation components to facilitate daisy-chaining, increasing flexibility and reliability.
- Power: Some competing industrial networks make it easier to distribute power, but Power-over-Ethernet (PoE) is advancing including a new version of 802.3af that makes more power available over the Ethernet communications cable. The primary remaining challenge is that the standard voltages used for industrial applications isn't the same as the 40 Vdc used for PoE.

Like any network, Ethernet has its limitations but they are becoming fewer every day.

If not designed and managed properly, increased integration of real-time control and business networks can increase security risks and vulnerabilities. But this risk can be managed through proper policies, procedures and network design so that the resulting system not only provides a fast reliable network, but also meets security requirements and insures that the integrity of the system is maintained at all times.

Standard Ethernet, unmodified through Layers 1-4, can handle most factory floor applications if proper network design rules are followed. Controlling the size and configuration of the network to limit the maximum latency/jitter makes it possible to determine the ranges within which deterministic behaviour can be guaranteed. But in a few cases, standard Ethernet simply won't work, necessitating the use of proprietary Ethernet protocols (see Sidebar, Ethernet Protocols).

It's best to limit the use of proprietary protocols because standard Ethernet provides not only low cost and high performance, but also the option of selecting best in class equipment from multiple suppliers with the knowledge that all components will interconnect and operate together reliably.

In addition, with standard Ethernet, technical support doesn't rely on one or two experts equipped with special tools. Instead, standard Ethernet allows the use of standard diagnostic tools and numerous experts to resolve any network problems quickly, thus maintaining system uptime.

## Making Connections

The capability to integrate from the automation network through the enterprise and potentially to the OEM supplier itself provides a number of benefits. Real time inventory management becomes possible for the industrial manufacturing facility, the OEM customer, as part and material usage information are made available. Recipes and production orders can be automatically downloaded and changed as required. Production information becomes available throughout the enterprise, often provided by automation components equipped with Ethernet ports and web server capability.

Troubleshooting becomes easier as a wealth of status information can be provided to not only OEM customers, but to the OEM itself. This allows remote support of machines and robots from the OEM's external experts to continuously monitor and troubleshoot the system.

The ability to bring the problem to the expert rather than requiring the expert to be physically at the equipment not only makes better use of limited expertise, but also meshes well with today's changing demographics. Baby boomers are retiring and taking their expertise, knowledge and experience with them—and as a consequence most OEMs and OEM customers find that they there are simply too few experts to go around.

In response, OEM customers are implementing plant floor information systems to capture and automate the associated business and manufacturing processes in an effort to mitigate the loss of knowledge by making the entire manufacturing system smarter. Fortunately, another demographic trend favors this trend as Millennials are by and large familiar with microprocessor-based technology and Ethernet, and as such are comfortable with migration to the smart manufacturing concept.

## Ethernet Protocols

As implied in Figure 2, standard Ethernet can support a wide range of protocols, and almost every modern industrial bus network has an Ethernet equivalent. Fortunately, the majority of Industrial Ethernet protocols such as EtherNet/IP and Modbus TCP use standard Ethernet.

However, protocols such as EtherCAT and Powerlink require some customized hardware in their Ethernet-based networks, with this hardware only available from a limited number of suppliers. In most cases the reasons for using a customized version of Ethernet are speed and determinism, specifically the need to ensure that message transfers between nodes are performed quickly in a definitive time. This high performance is often needed for multi-axis machine control and other applications.

In theory, because they all share the same lower layers of the OSI model, multiple protocols can run simultaneously on the same Ethernet network, but in most industrial applications only one protocol is run on the network. Industrial communications systems are often complex, and keeping protocols separated makes security and maintenance simpler.

The differences between modified and standard Ethernet are that standard Ethernet doesn't make any changes to Layers 1 through 4 of the protocol stack. Modified versions of Ethernet will either replace one of these layers, or substitute the information inside one part of the Ethernet frame with something different. The result is that it's no longer possible for COTS routers and switches to determine where to send messages.

As shown in the Figure 3 pie chart, many different Ethernet protocols are available for use in the industrial arena. Considering only those that use standard Ethernet, there are three primary players in this space. In the United States, EtherNet/IP is most widely used and would be the normal migration path upward from DeviceNet as both protocols are supported by the ODVA organization. In Europe, ProfiNet is taking center stage and is the migration upward from Profibus, with both protocols supported by the same organization.

Though not shown in this pie chart, Toyota's Toyopuc Ethernet is the leading Ethernet protocol in Asia. Usage of this protocol is largely driven by the Japanese automobile industry as Japanese OEMs are dedicated to using Toyopuc as the standard for all Toyota automotive plants and suppliers, both in Japan and in other countries.

There are PLC manufacturers which use their own Ethernet protocol, but that trend is gradually shifting. For instance, Modbus TCP is an Ethernet protocol that used standard Ethernet for communications, but inside the message traffic is still the Modbus based protocol. And while Modbus TCP has a following, it's main proponent Schneider Electric is also a member of ODVA, and as such is now including EtherNet/IP ports on a some of their PLCs.

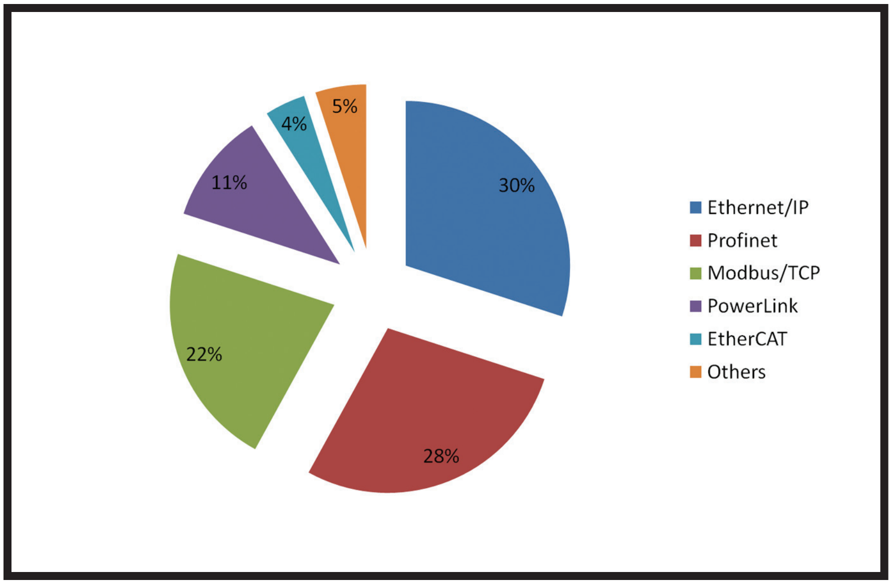


**Figure 3**: Ethernet Protocol Breakdown
Reference IMS Research "The World Market fir Industrial Ethernet - 2009 Edition"

In addition to sending data to OEM customer experts, it's also possible for the equipment to transmit real time health information to the OEM. The OEM can then remotely monitor their machines or robots, even offering this assistance on a contract basis and including sophisticated services such as predictive maintenance and throughput optimization, thus maximizing machine uptime and output.

The additional advantage to the OEM of remote monitoring is that they are now able to gather data from a large number of installations. Analysis of this data can reveal common failures, allowing OEMs to improve reliability by adding features and diagnostic tools to both existing machines through upgrades and to new machines.

Expanding this concept to the next logical step, robust Ethernet networks will allow broad swaths of functionality to be delivered by OEMs as services. This makes it possible for the company that best understands the machine or robot

to optimize their customer's operations for a nominal services fee. This frees up other resources at the customer's facility, allowing them to focus on the overall production process rather than the equipment used to run it.

Using standard Ethernet and common protocols as well as the abovementioned standards also makes it possible for each machine in an assembly line to communicate with the next unit in the line regarding its status and utilization. If each piece of equipment in one or more assembly operations knows the status of its neighbors, it's possible to make maximum use of each machine to optimize throughput across the facility by synchronizing machine inputs and outputs.

If one of the machines is experiencing some form of difficulty or backlog, the result no longer has to be an unscheduled full shutdown and start-up with the associated expenses and lost production. Instead, the upstream machine's output can either be transferred to a parallel line, or the machine's output can be reduced down until the backlog is cleared.

The key to deriving benefits from all these internal and external connections is high reliability, beginning with the equipment used to build the network.

**Figure 4**: Large OEM machinery automation systems often benefit from implementing industrial Ethernet to link HMIs, controllers, I/O, motor drives and sensors.

## Why Industrial

Despite the fact that Ethernet used in the business environment is the same as that used in industrial applications, the demands on the equipment itself are very different. Because any system is only as good as the physical infrastructure on which it's built, it's imperative that the equipment chosen for the application is specifically designed for the environment in which it will be used.

Some of the biggest differences between the typically well controlled office environment or a server room and the plant floor include:

- Temperature: Industrial temperature ranges can cover the spectrum from -40 degrees C to greater than +70 degrees, with the expectation that the no additional components for heating or cooling be required for the equipment to stay operational.
- EMI/RFI: Industrial plants have many sources of EMI/RFI interference including large power cables, big motors, and other equipment such as robot welders.
- Humidity/Moisture: This includes not only ambient moisture such as rain, but can go so far as complete immersion in not only water but a range of other fluids as well. But typically, the requirements are for protection from non-condensing liquids only along with the ability to resist spray. Meeting this requirement is normally accomplished by specifying NEMA 4 or IP67 protection.
- Vibration: Because there's constant motion in a plant, from either the equipment itself or as a result of the fluid in a flowing process, all equipment connected to the process is subject to vibration. This vibration can cover a broad range of frequencies and amplitudes.
- Motion/Flexing: Assembly lines incorporate a large number of moving parts such as robot arms, conveyors, and pick and place systems. This movement is often in multiple directions at high rates of speed.
- Power: The power provided to automation and communication components in an industrial setting is often dirty, filled with spikes and electrical noise. Industrial grade components can typically handle a wide range of input voltages, and can tolerate power that's not as clean as that provided in an office environment.
- Mounting: Industrial settings vary considerably, so automation and communication components must be adaptable to a wide variety of mounting formats including DIN rail mount, panel mount, and rack mount.

As can be seen from the above list of requirements, standard COTS equipment designed for the office environment will not provide the degree of protection required in an industrial setting.

Automation and Ethernet components designed for industrial use are readily available, but cost is somewhat higher than their commercial counterparts, tempting some to illusory savings. Industrial networks require as close to 100%

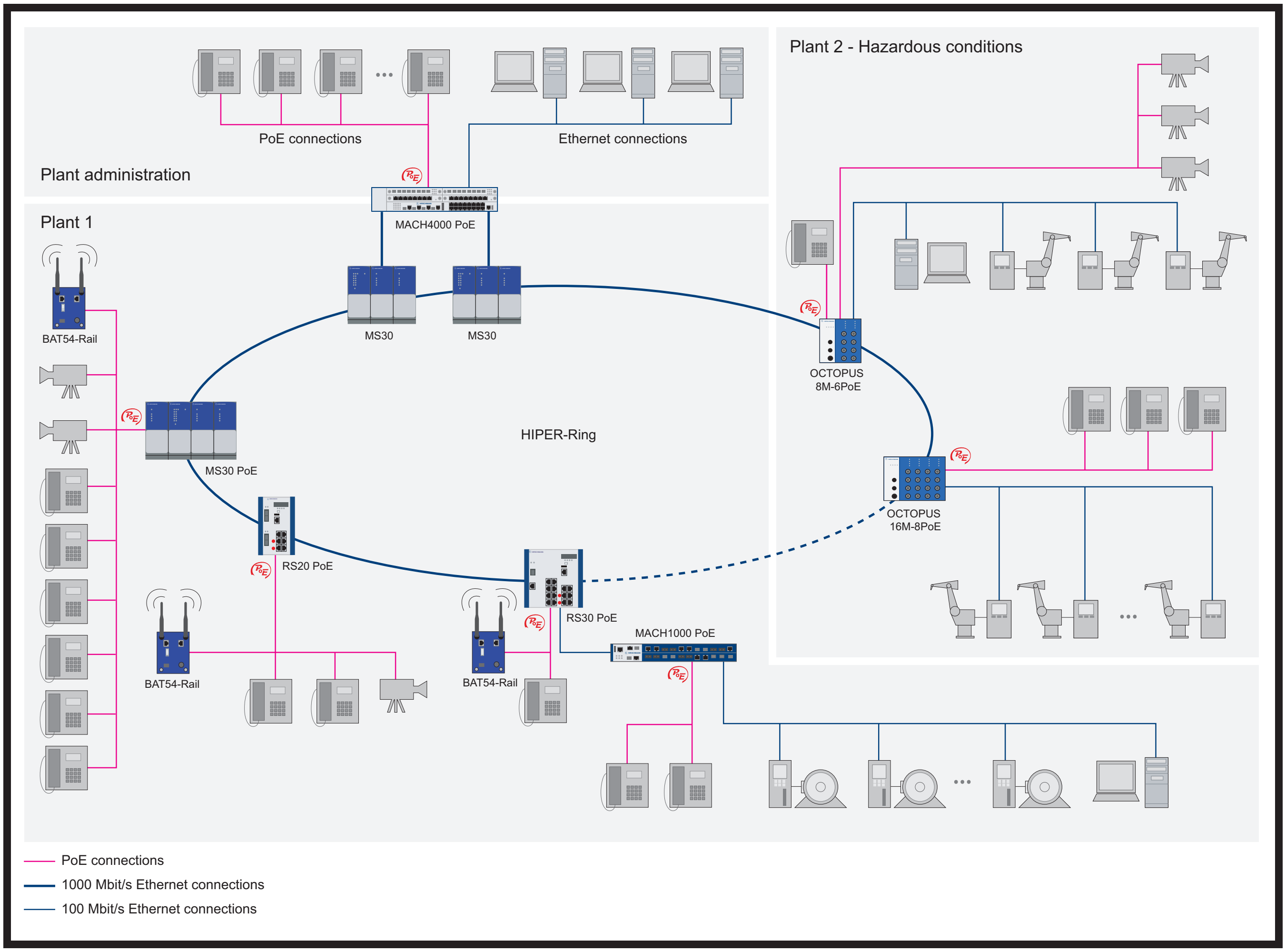


**Figure 5**: Ethernet network depicting the integration of plants and office administration using a variety of Ethernet managed switches, wireless routers, rugged on-machine IP 67 managed switches with PoE, 1000 Mbit/s and 100 Mbit/s Ethernet connections.

availability as possible not only because of the huge financial impact of an unscheduled outage in terms of lost production, rework and possible machinery damage—but also because of the potential risks to safety and the environment.

In some larger manufacturing facilities, a single unscheduled outage can result in costs equivalent to days or even weeks of anticipated profits, so the incremental cost to purchase industrially-rated components is well worth it.

Just as important as selecting the right industrial grade components are the connections among the components. In the case of Ethernet, these connections are typically Cat 5e or Cat 6 cable. Physical cable integrity and electrical performance must be maintained or deterioration of the signals will lead to failure of the network.

Many machines and robots continually place Ethernet communication cables under duress by movement and consequent required cable flexing. Flex cycles cause stress on cables and connections, often resulting in premature failure. Data integrity can also be compromised because of changes to cables during these flexing operations, with the resulting risk that data communication interruptions will occur.

Fortunately, high flex industrial Ethernet cables are available that can reliably operate in continuous flex environments without signal interruption. These special cables are normally used to implement Ethernet on robots and machines with these types of requirements.
As with industrial grade Ethernet components, upfront costs are somewhat higher for high flex as compared to standard cables, but the extra expense is well worth it to guarantee reliability at an acceptable level.

Ethernet is the networking technology of choice in office and commercial environments, and it's

also quickly becoming the standard in industrial settings. But because the plant environment isn't the same as the office milieu, both the design and the components must be appropriate for the task at hand. Extra cost spent up front to purchase industrially rated components and employ proper design expertise will be more than repaid over the life of the network in terms of more uptime and greater throughput of the manufacturing process.

## Conclusion

Ethernet and other industrial networks are fast replacing hard wiring in machine and robot builder OEM applications. The savings in wiring costs alone often justifies use of industrial networks, while the additional benefits outlined above and in Table 1 give further reasons for OEMs to upgrade to Ethernet.

Although non-Ethernet industrial networks save money over hard wiring, they don't work as well as Ethernet when it comes to providing other benefits, particularly connectivity to the enterprise and to remote users. Ethernet networks have particular advantages in these areas because of the wide acceptance of Ethernet beyond the plant floor. Simply put, it's easier to interface one Ethernet network to another than to interface a non-Ethernet network to an Ethernet network.

Ethernet is the networking technology of choice in office and commercial environments, and it's also quickly becoming the standard in industrial settings. But because the plant environment isn't the same as the office milieu, both the design and the components must be appropriate for the task at hand. Extra cost spent up front to purchase industrially rated components and employ proper design expertise will be more than repaid over the life of the network in terms of more uptime and greater throughput of the manufacturing process.

**Table 1: Advantages of Ethernet in OEM Applications**

1. Saves money over hardwiring
2. Provides diagnostics
3. Easier to interface to the enterprise
4. Easier to implement remote connectivity
5. Superior price/performance ratio
6. Clear upgrade path from existing networks
7. Existing base of experienced users
8. Wired and wireless solutions can co-exist

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