June 2017

Maximizing Ethernet Life Cycle Reliability Using Structured Cabling

Don't Take a Bath in Point to Point Connectivity

Introduction

Industrial Ethernet network reliability depends heavily on successful network packet delivery. Network packets are the lifeblood of manufacturing—controlling equipment, collecting data, sending reports, capturing video, etc. When network packets fail to arrive at their destination device, such as an Industrial Ethernet switch, equipment may stop or critical production data may vanish, leading to costly downtime. Deploying proper structured cabling is a proven reliability strategy that eliminates or minimizes long term (minutes or hours) or intermittent (lasting seconds to sub-seconds) network packet failures throughout the network life cycle.

Control engineers, OT staff, and IT professionals often assess network reliability according to the perceived failure rate of active gear (e.g., network switch, firewall, etc.) and the components (e.g., plugs, jacks, and cables) that comprise the Ethernet channel. A common perception is that point to point cabling is more reliable than structured cabling because it has fewer parts compared to structured cabling. This assumes a constant failure rate over time. However, the failure rate can change over the network life cycle during installation, normal operation, and wear out because each of the life cycle phases may have different impacts and failure rates.

Most failures occur during installation, then the failure rate settles down where failures are random. At some point, components wear out and the failure rate increases. The term "bathtub curve of reliability" refers to the graphing failure rate over time. This paper compares the reliability of structured cabling versus point to point cabling from installation to end-of-life within the context of the reliability bathtub curve.

Background

There are two primary ways to deploy a network infrastructure in an industrial environment:

1. Point to Point—A point to point channel is a field installation where an installer terminates a field terminable RJ45 plug, (e.g., Panduit® IndustrialNet™ Category 6A RJ45 field terminable plug) to both ends of the cable, connecting two devices (Figure 1).

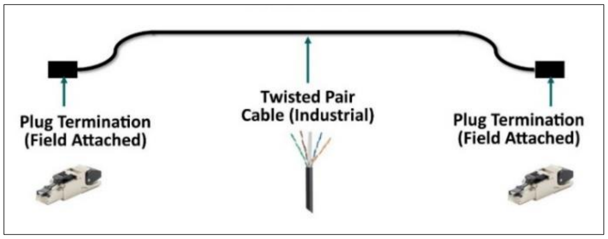

Figure 1. Example of a point to point channel.

2. Structured Cabling—Structured cabling is a planned and designed installation divided into subsystems (Figure 2a). The system follows TIA-1005 *Telecommunications Infrastructure Standard for Industrial Premises* and ISO/IEC-24701 *Information Technology—Generic Cabling - Industrial Premises*.

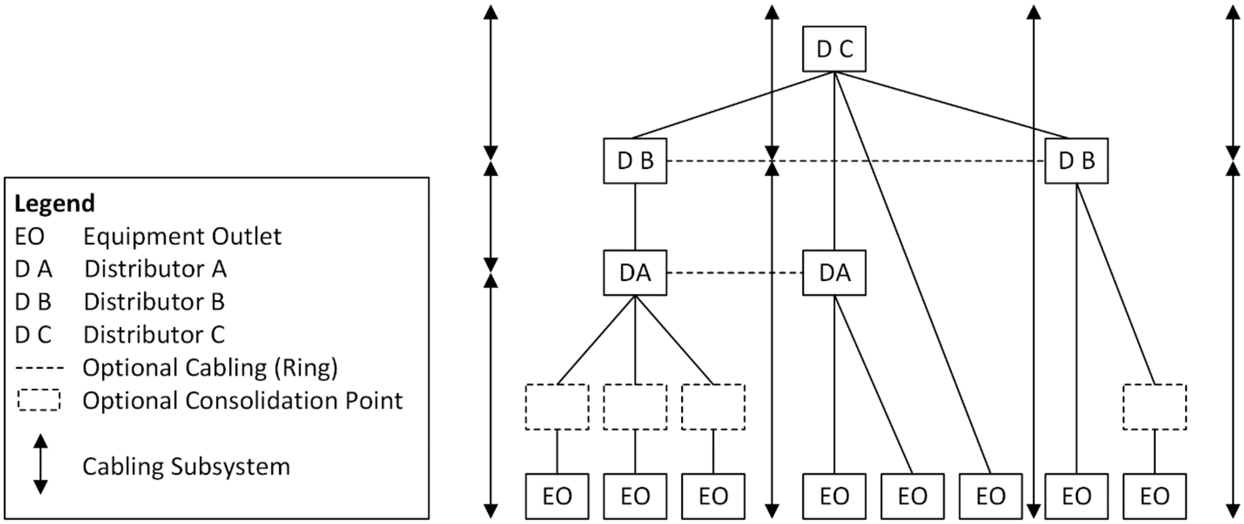

Figure 2a. Elements of generic cabling topology.

Within structured cabling, the focus of this paper is the Ethernet structured cabling channel, (i.e., connectivity) between distributors. A distributor may have switches (distribution or access) or can be a passive consolidation point. Connectivity includes patch cords, patch panels, and backbone cabling. A point to point connection does not have distributors and connects a central factory switch to the end device on the plant floor in a home run fashion (Figure 2b).

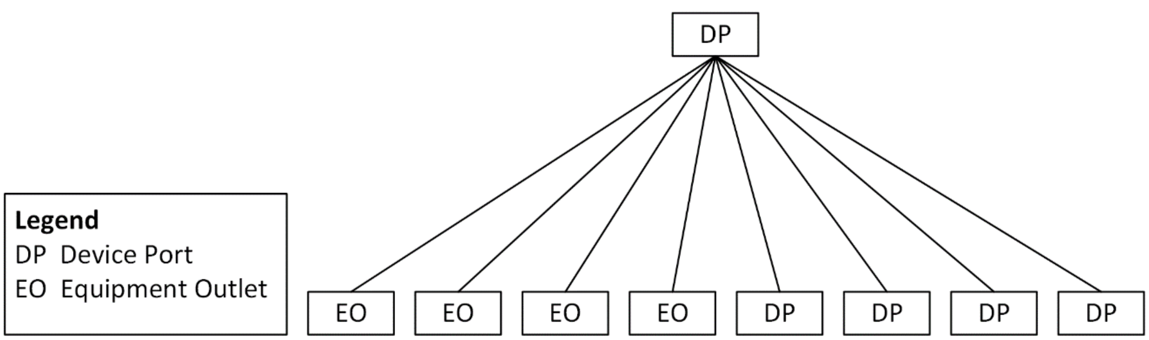

Figure 2b. Home run cabling.

The cabling between the distributors is a stationary solid conductor routed in a pathway such as a ladder, tray, or conduit. The installer terminates the cabling to a jack in a rack unit (RU) or DIN form factor patch panel. Tested and validated patch cords connect the active equipment to the jack on both ends, completing the channel (Figure 3). Structured cabling has proven to work well for these implementations.

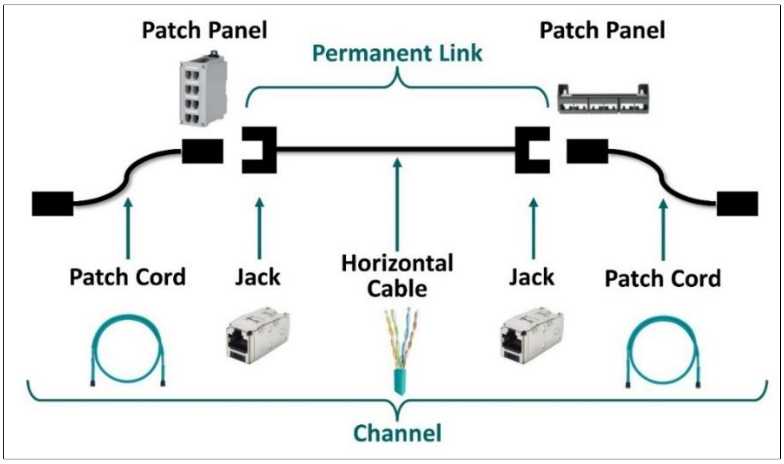

Figure 3. Structured connectivity diagram.

A common approach to estimate reliability is to add all failure rates of jacks, plugs, and cable in a channel. For a point to point connection, there are four interface failure points, (i.e., plug and cable termination to plug). A structured cabling channel has 12 potential interface/failure points to include twice as many plugs with termination and jacks. This assumes a constant failure rate throughout the network life cycle. However, a constant failure rate may not address all cases throughout a network life cycle. The next section explores this scenario.

Industrial Ethernet Failure Modes

When designing for reliability, it is important to understand how network packet delivery fails. There are two failure modes:

1. Packet Delivery Failure—The packet signal is attenuated, distorted, or introduces aliases, causing erroneous packet decode. This leads to excessive Bit Error Rate (BER) and the following conditions can cause it: high channel resistivity due to poor termination or port contamination; high electrical noise from motors or servo drives; and high channel inductance and capacitance.
2. Network Cabling Disconnect—The Ethernet channel has been severed due to an accidental unplug, cut cable, or cabling loosening from the jack, plug, or connector.

Although the causes of these two failure modes are drastically different, losing network packets, whether intermittent or long term, impedes manufacturing by resulting in downtime, erroneous data, or delayed equipment commissioning.

Reliability Bathtub Curve

It is impossible to predict when a failure will occur. The best estimate is the probability, expressed in failures per hour: the lower the failure rate, the higher the reliability. The challenge is that the failure rate can rise or fall, depending on where it occurs in the network life cycle. Since the failure rate is not constant for an Ethernet channel and changes throughout the network life cycle, it is important to treat network reliability in a manner other than adding up the failure rates of components in a network channel.

Typically, the installation phase of the life cycle has high failure rates. Once the installer addresses any issues during this phase, the failure rate settles down and is constant. During the life cycle, components wear out at an accelerated rate. Overlaying both the premature failures with the wear out graph provides an accurate depiction of the network cable life cycle.

The graph resembles a bathtub where the left side of the graph is steep, the middle is flat, and the right side slopes up. This is the reliability bathtub curve and exists for all kinds of products and physical deployments**,** including the Ethernet channel (Figure 4).

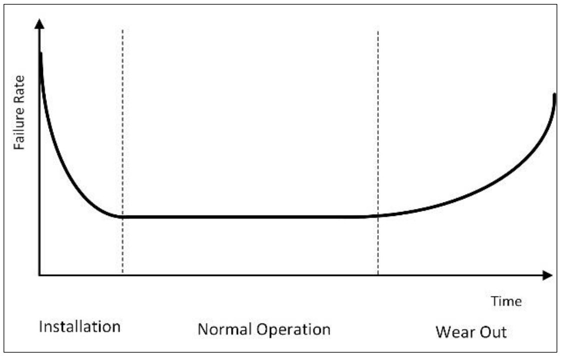

Figure 4. Bathtub curve of reliability.

There are three phases to the bathtub curve:

1. Installation—This phase starts at time zero. The curve has a high failure rate but rapidly decreases. This is due to improper assembly, installation, or rough handling.
2. Normal Operation—This part of the curve flattens throughout the intended useful life where failures are random or due to human error.
3. Wear Out—This is the point in the curve where the failure rate rises because of component degradation. The harsh environment is a big factor affecting Ethernet channel life. Consequently, the failure rate may rise prior to the intended useful life if cabling and connectivity are not appropriate for the environment.

There are different strategies and techniques to drive down the failure rate in each life cycle phase. For the installation phase, the goal is to flatten the curve as shown by the red arrows in Figure 5. The following factors impact this part of the curve.

- Installer skill and care
- Validated and tested channel
- Superior product design

The goal for the normal operation phase is to drive down the curve as shown by the blue arrows in Figure 5. The following factors influence this part of the curve.

- Inappropriate maintenance activities
- Human error
- Superior product design

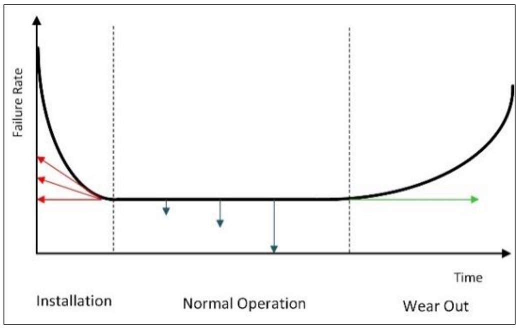

Figure 5. Driving improved reliability.

The wear out phase should be a business's expectation for the network life. During the network life cycle, wear out will occur at some point. Businesses typically expect network infrastructures to last 20 years. Therefore, the wear out point, as shown by the green arrow in Figure 5, should not occur before the expected life. If it occurs, the network will prematurely wear out, generating more costs than expected. The network infrastructure specification and design heavily influence this part of the curve. Some of the causes of premature wear out are:

- Inappropriate cable jacket for the environment
- Poor cable management with tight bends, abrasion, or flexing
- Lack of strain relief where cable loosens
- Crushing
- Added equipment, (e.g., heat, vibration, or EMI), that may change the environment

Structured vs. Point to Point Reliability Life Cycle

During installation, structured cabling requires different considerations than point to point cabling. For example, an experienced certified installer should deploy structured cabling. Electricians who may not be familiar with networking usually install point to point cabling ad hoc with field terminable plugs and only perform continuity testing, (i.e., green light). Although performance testing is essential to establish channel performance prior to operation, it is unlikely that installers performance test point to point cables. The best approach for cable installation is to use a certified installer such as an Industrial Automation Infrastructure Deployment Partner to test and validate the installation. RJ45 jacks facilitate link testing better because it is a natural demarcation point. Also, test equipment addresses link testing with RJ45 jacks, which is a significant advantage of a structured cabling system.

Another consideration is reliably terminating to an RJ45 jack instead of a plug. For a plug, alignment of the conductors is critical and can be difficult and hard to see. If not prepared correctly, the channel may not function or may experience intermittent failures due to high resistivity or intermittent contact. RJ45 jacks are easier to terminate, leading to greater reliability. An RJ45 jack design such as a Panduit RJ45 Mini-Com® jack (Figure 6) has IDC contacts for better cable balance, which is affected by unwinding cable pairs to terminate. Also, it has a reliable connection with the conductor and maintains the twist during installation. If a punchdown RJ45 jack installation is untwisted too many times, signal degradation can occur because of the comprised noise canceling feature of the twist. A Panduit RJ45 Mini-Com® jack provides strain relief and prevents the conductor from being pulled out compared to a punchdown RJ45 jack.

The last part of the channel is the connection of the jack to a device using a patch cord. Using tested and validated patch cords from Panduit ensures reliable connectivity to the jack and device. Often, untested and low-cost patch cords are the weakest link in a structured cabling channel. Following structured cabling installation recommendations flattens the failure rate curve for the installation life cycle phase.

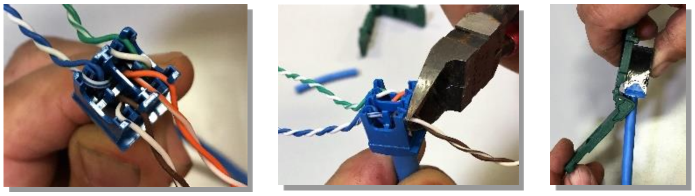

Figure 6. Panduit Mini-Com® jack.

During the normal operation phase, installers should avoid improper maintenance or human error. A structured cabling system is far easier to maintain compared to a point to point system, leading to fewer failures. A well-designed structured cabling channel has built-in growth for connecting new equipment and devices. Installers run extra cables throughout the facility, for example, multiple drops to a location. Adding horizontal cable later can disrupt existing cable connectivity and lead to failure. Installers add new equipment and devices simply and quickly for a reliable patch cord connection, especially with tested and validated patch cords. Point to point connections cannot accommodate growth and installers add them ad hoc as needed, usually under pressure to quickly finish the deployment, which disrupts production.

One way to prevent human error and improper maintenance is with proper labeling. Labeling eliminates the guesswork, which can be detrimental to production. The backbone cable, cabinet/rack, patch panel, patch panel port, and patch cord are all points that operators can label. The labeling should follow the TIA-606 standard where a label has both “from” and “to” connections and the enclosure/rack, patch panel, and port designation (Figure 7). Point to point cabling can get buried, making it hard to read labels, which leads to improper connects or disconnects.

Figure 7. Labeling (left) and color band (right).

Another strategy to eliminate mistakes during the normal operation phase is to implement the color coded RJ45 jack, keyed RJ45 plug/jack, color coded cabling, color coded labels, and color bands. With structured cabling, there can be many uses and levels of color coding. For example, the backbone cabling can be blue and white to identify redundant A and B Ethernet channels, the port can be color coded for the manufacturing area, and a color band can specify patch cords for the VLAN designation. Although point to point has color coding options such as the cable jacket color, it lacks the diversity that structured cabling achieves.
By providing a better picture of connectivity with color coding or keyed ports, moves/adds/changes (MACs) are better facilitated, ensuring proper maintenance. This leads to lower failure rates due to maintenance during the normal operation phase, driving down the curve.

When a channel experiences a high BER or dropped packets, rapid troubleshooting is essential to minimize downtime. As stated earlier, a structured cable channel better accommodates troubleshooting because the RJ45 jack is a natural demarcation point. Test equipment can easily and quickly assess the permanent link. If the permanent link testing is within specification, the patch cord could cause failure but an installer can quickly swap it out. If the permanent link is severed and there are spare channels, the installer can bring a new channel online in minutes. Most test equipment cannot assess a point to point channel. Therefore, to replace the channel (if needed), an installer can run new cable. This can take hours or days, depending on the distance or interference that the installer can encounter.

The last network life cycle phase to consider is wear out. This is the point where cabling strands may become bare or break, plugs/jacks corrode, and cable jackets become brittle. The environment (e.g., UV, oil, weld splatter, solvents, paints, flex, temperature, etc.) also impacts cable jacket wear out (Figure 8). To prevent hazards to human health and safety and protect equipment, manufacturers provide cable jacket ratings, which can vary.

Figure 8. UV/temperature damage (left) and oil damage (right).*

Table 1 highlights the differences in cable jacket construction and the protection it provides. By following the TIA-1005 MICE environmental designation for the various manufacturing areas (i.e., distributors), a structured cabling approach accommodates various cabling types best suited for the environment by subsystem (Figure 2a). For example, a production environment with the highest M_3 value (Mechanical on a scale of 1-3, with 3 being the harshest environment) due to flexing should use a high flex cable such as the Panduit IndustrialNet™ Category 5e SF/UTP copper cabling (see TIA-1005 for MICE explanation). A point to point cabling strategy does not accommodate optimized cabling by manufacturing area hazard because it may traverse many areas with varying degrees of harshness. In addition, the installer may need to use a point to point cabling jacket for the harshest traversed area, driving up deployment costs. A worse scenario is if the installer uses a lesser cable jacket to address an underestimated hazard.

**Courtesy of General Cable*

*Table 1. Cable Types and Properties.**

Material/Property	Premise (PVC)	Industrial PVC	FRPE/FRPO LSZH	FEP
Typical Tensile Strength (PSI)	**2000 - 3100**	2000 - 3100	1500 - 2500	3000 - 4000
Elongation	**200 - 350**	200 - 350	150 - 200	200 - 500
Brittle Point (°C)	**0 to -20**	-20 to -40	-20 to -60	-40 to -20
Oxygen Index (%)	**30 - 50**	40 - 50	25 - 45	90+
Oil Resistance	**N/A**	OIL RES	OIL RES	Varied
UV Resistance	**N/A**	SUN RES	SUN RES	Varied
Max Temp Rating (°C)	**75**	105	105	200

Another possibility of wear out is cable flexing. This is especially true for point to point channels with solid copper cable. MACs involve cable flexing which will cause a solid point to point cable to break over time. A solid conductor has better electrical performance compared to a stranded conductor and costs less. This is one reason installers prefer a solid conductor to traverse longer distances throughout the plant. The solid conductor is best implemented with a structured cabling approach where the installer secures the structured cabling permanent link in a pathway such as a tray or J-hook that holds it in place.

Cable designed to flex, such as a patch cord, will be stranded. There are trade-offs because the stranded cable attenuates the signal and has a shorter reach. If an installer uses stranded cable for a point to point connection, it can only run 80m. A short, stranded patch cord that is part of a structured cabling system has negligible attenuation and is the best choice to connect devices due to flexing during MACs and maintenance. A structured cabling implementation balances the strengths of a solid conductor cable for long reach and stranded patch cords where flexing may occur.

Other Considerations

A point to point channel using heavily shielded or jacketed cable may not fit into a standard or field terminable plug. RJ45 jacks accommodate different sizes. The Panduit Mini-Com® TX6A™ 10Gig™ shielded jack module offers a larger jack diameter for extreme environments. Another consideration is installing field cable in a high voltage panel that requires 600 V rated cable. A point to point connection would require the entire channel to be a more expensive 600 V rated cable. A structured approach would only require a 600 V rated patch cord in the enclosure at a lower cost. The backbone cable is not required to be 600 V rated.

The ends of cable runs near equipment are the most susceptible to damage. With point to point systems, if damage occurs, installers must replace the entire run or cut out and splice the damaged section, creating an additional failure point. With structured cabling systems, a damaged patch cord is easy to remove and replace. This speeds repair, minimizing downtime. Table 2 compares structured and point to point cabling deployment examples. In some cases, point to point cabling is an acceptable solution, especially when connecting devices in a control panel in a device level ring.

**Courtesy of General Cable*

Table 2. Deployment Examples for Structured and Point to Point Cabling.

Primary Considerations	Structured Cabling	Point to Point Cabling
Meet Design Specifications	• High cable quantity – many cables from panel to machine • Customer verification and testing required from installer • Warranty	• Low cable quantity – few cables from panel to machine • Ring or linear topology for reach beyond 100M where distance between connection is < 100M
Network Longevity (Future Proof)	• Designed in spare ports	• Difficult to have spare connectivity
Maintainability (Moves, Adds, Changes)	• Environments with multiple changes occurring • Cable slack is required	• Environments with minimal changes occurring • Slack cabling is undesired and precise cable lengths are required
Installation	• Multiple points of connectivity • Horizontal cabling is largely untouched	• Quick and easy installation • Where tight bends or moderate flexing is required • Areas where it is impractical or impossible to mount a patch panel or other horizontal cable jack interface

Conclusion

A structured cabling implementation better addresses failures throughout the network life cycle compared to point to point connectivity. In addition, structured cabling minimizes premature failures during useful life compared to point to point connectivity. Deploying a structured cabling system appears to be the best choice to ensure network packet delivery and to safeguard manufacturing dependability.

Referenced Resources

- TIA-1005 Telecommunications Infrastructure Standard for Industrial Premises
- ISO/IEC-24701 Information Technology – Generic Cabling - Industrial Premises
- TIA-568 Commercial Building Telecommunications Cabling Standard
- TIA-606 Administrative Standard for Telecommunications Infrastructure

DISCLAIMER: This Technology Brief is for informational purposes only. Each customer should evaluate its own requirements prior to determining whether a structured cabling system or point to point connectivity solution best fits its needs.