# The Software-Defined Manufacturing Revolution

How time-sensitive networking and workload consolidation are combining to reshape real-time software industries


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## TenAsys® enables deterministic workload consolidation and converged infrastructure deployments — all at new levels of flexibility, productivity, and efficiency. We help customers combine next-gen tech and legacy IP to innovate at scale and unlock digital transformation.

For more than 40 years, TenAsys® solutions have proven themselves in industrial control and automation, robotics, medical electronics, test and measurement, aerospace and defense, and other demanding applications. We leverage this experience in a consultative approach that guides technology-driven organizations from early-stage technical discovery through the development of long-life cycle solutions and product roadmaps.

At TenAsys, we prioritize ease of use and productivity in everything we do. That's why our INtime® portfolio targets off-the-shelf PC platforms and integrates with familiar tools like Microsoft* Visual Studio, speeding development and mitigating the need for the expensive experts who are required for open-source and custom environments.

TenAsys solutions are strengthened by close relationships forged with other industry leaders. We integrate with best-in-class technologies from Intel*, AMD*, Microsoft, VMware*, Real-Time Systems, and other cutting-edge hardware and software suppliers.

Along with our broad ecosystem, we offer ready-to-use solutions to streamline your development process, significantly reducing effort and investment. Developers can leverage the design knowledge from our partnerships to optimize and accelerate their designs.

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INtime®

INtime® is a deterministic RTOS that can run on off-the-shelf industrial PCs with minimal setup, working alongside general-purpose OSs like Microsoft* Windows and Linux. Support for popular hypervisors and inclusion of real-time networking features means that applications as diverse as motion control, enterprise software, and HMI can all run on a single, consolidated system.

tenAsys®

TenAsys® streamlines the integration of operational and enterprise technology, giving users a jumpstart on transformational capabilities like edge analytics and AI. Our INtime® platform facilitates deterministic control as well as edge-to-cloud connectivity, revealing critical data for immediate action. And it provides future-ready scalability, from a single product to an entire converged infrastructure.

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# Revolutionizing Industrial Automation: Workload Consolidation and Time-Sensitive Networking

The industrial sector is on the brink of a significant transformation. As we progress deeper into the era of Industry 4.0, the traditional boundaries between Information Technology (IT) and Operational Technology (OT) are blurring.

At the heart of this evolution are two key initiatives: Workload Consolidation and Time-Sensitive Networking (TSN). These are at the core of the evolution towards Software-Defined Manufacturing, shifting how industries operate, innovate, and grow.

## The Drive for Innovation in Industrial Environments

Traditionally, industrial environments have been characterized by rigid, hardware-centric architectures. Proprietary systems, isolated networks, and purpose-built controllers have been the norm, resulting in operational silos that hinder efficiency and innovation. However, in an increasingly competitive global marketplace, industries can no longer afford the limitations imposed by these legacy approaches.

*"Identifying the right technology (47%) and compatibility with their existing systems (44%) are the biggest challenges manufacturers face when planning investments in new software."*

*— 2024 Tech Trends Survey, Gartner Digital Markets*

The pressure to improve efficiency, reduce costs, and accelerate innovation is driving a shift towards more flexible, software-driven industrial ecosystems. Yet, 47-percent of 481 manufacturing industry purchasing decision makers surveyed for Gartner Digital Markets' 2024 Tech Trends Survey selected "identifying the right technology" as their biggest challenge in planning new software investments. Forty-four percent cited compatibility with existing systems as their most significant hurdle.

Now, workload consolidation and time-sensitive networking have emerged to reduce those barriers and enable the software-defined industrial automation revolution.

## Workload Consolidation: Unlocking Efficiency and Innovation

Workload consolidation represents an architectural evolution in how industrial computing resources are utilized. By combining multiple discrete functions onto a single industrial computer, this approach offers numerous benefits:

1. **Cost Reduction**: Consolidation significantly decreases both capital expenditures (CAPEX) on hardware and operational expenditures (OPEX) related to maintenance and energy consumption.

2. **Enhanced Performance**: Tighter coupling between different functions leads to lower latency and improved communication, enabling more responsive and efficient operations.

3. **Improved Security**: Hardware partitioning allows for isolation of critical functions, enhancing overall system security and reliability.

4. **Accelerated Innovation**: By adopting cloud-native development workflows, industries can rapidly deploy and iterate on new functionalities.

5. **Future-Proofing**: Consolidated systems are more adaptable to changing requirements, ensuring longevity of investments.

The concept of virtual Programmable Logic Controllers (vPLCs) exemplifies the potential of workload consolidation. Instead of deploying numerous physical PLCs across a factory floor, multiple vPLCs can be implemented as co-resident software instances on high-performance industrial PCs. This not only reduces hardware costs but also allows for more dynamic and flexible control strategies.

## Time-Sensitive Networking: Enabling Real-Time Industrial Communication

As industrial systems become more interconnected and data-driven, the need for deterministic, real-time communication becomes paramount. Time-Sensitive Networking emerges as the solution to this challenge, offering a standardized approach to achieving predictable, low-latency communication over Ethernet networks. TSN brings several critical capabilities to industrial environments:

1. **Determinism**: By providing precise time synchronization and traffic scheduling, TSN ensures that critical data is delivered within strict time constraints.

2. **Convergence**: TSN allows for the coexistence of time-critical control traffic and standard IT traffic on the same network infrastructure.

3. **Standardization**: As an IEEE standard, TSN promotes interoperability between devices from different vendors, breaking down proprietary barriers.

4. **Scalability**: TSN can scale from small, localized networks to large, facility-wide or even multi-site deployments.

TSN serves as the connective tissue required to make concepts like software-defined manufacturing a reality. It enables the integration of cyber-physical systems, IoT devices, and cloud services, allowing operators to manage all these components as part of a single, coherent, virtualization-ready infrastructure.

## Overcoming Implementation Challenges

While the benefits of workload consolidation and TSN are clear, their implementation comes with challenges:

1. **Legacy Integration**: Many industrial environments have substantial investments in existing systems that cannot be easily replaced.

2. **Complexity**: Configuring and managing TSN networks, especially in large-scale deployments, can be complex and require specialized expertise.

3. **Skills Gap**: The convergence of IT and OT necessitates a workforce with a broader skill set, combining traditional automation knowledge with IT and networking expertise.

4. **Security Concerns**: As industrial systems become more connected, they also become more vulnerable to cyber threats, requiring robust security measures.

To address these challenges, technology providers are developing tools and platforms that abstract away much of the underlying complexity. For instance, real-time operating systems (RTOS) like TenAsys® INtime® are evolving to provide out-of-the-box support for TSN, simplifying the development and deployment of time-sensitive applications.

## The Future of Industrial Automation

The convergence of IT and OT, powered by workload consolidation and TSN, is not just a technological shift—it's a fundamental reimagining of how industries operate, innovate, and grow. As these technologies mature and become more widely adopted, we can expect to see:

1. **Increased Flexibility**: Industrial systems will become more adaptable, capable of quickly reconfiguring to meet changing production demands.

2. **Enhanced Efficiency**: By consolidating workloads and optimizing network communication, industries can significantly improve their operational efficiency.

3. **Improved Decision-Making**: Real-time data access enabled by TSN will allow for faster, more informed decision-making at all levels of industrial operations.

4. **New Service Opportunities**: The ability to remotely manage and update industrial systems will open up new service models for equipment manufacturers and system integrators.

5. **Accelerated Innovation**: With more flexible, software-driven systems, industries will be able to innovate and deploy new capabilities more rapidly than ever before.

## Embracing the Industrial Digital Transformation

The industrial sector is at a pivotal point in its evolution. Workload consolidation and TSN are paving the way for more efficient, flexible, and innovative industrial environments. By embracing these initiatives, industries can break down the barriers between IT and OT, unlocking new levels of efficiency, innovation, and competitiveness. The future of industrial automation is here, and it's more connected, more responsive, and full of possibilities.

## What You'll Find in This Ebook

This ebook provides a comprehensive exploration of the technologies driving the future of industrial automation. Read on to discover:

1. **An in-depth look** at how consolidating multiple functions onto a single industrial computer can unlock efficiency and innovation in industrial systems.

2. **How workload consolidation** can help ensure today's investments will support tomorrow's technologies.

3. **Why TSN is the foundation** of real-time network convergence and its role in enabling software-defined manufacturing.

4. **Strategies for abstracting** the configuration complexity of TSN to accelerate its mass adoption.

5. **How TSN is poised** to transform Industrial IoT, bridging the gap between insights and outcomes.

This e-book delves into the technical details, practical applications, and potential benefits of these technologies, providing you with the knowledge to navigate the evolving landscape of industrial automation.

# Workload Consolidation: Unlocking Efficiency and Innovation in Industrial Systems

BY BRANDON LEWIS, EMBEDDED TECHNOLOGY INDUSTRY ANALYST

Success in the industrial sector requires a relentless focus on efficiency. In recent years, this pressure has brought increased attention to workload consolidation, which combines what were once multiple discrete functions into a single industrial computer. Not only does this cut costs, but it also unlocks technical capabilities that can improve performance, security, and innovation.

The cost benefits alone present a compelling argument. Consolidating workloads onto a single platform significantly reduces the number of systems required, leading to substantial CAPEX savings on hardware and associated infrastructure. Infrastructure management, maintenance, and resource consumption can realize bigger savings, with operational expenditures (OPEX) falling precipitously under a workload consolidation paradigm.

Now, partnerships are emerging around workload consolidation technology stacks based on off-the-shelf hardware and software solutions that empower industrial users to realize those efficiencies. For instance, leading embedded software supplier TenAsys® is pairing its real-time INtime® software platform with multicore Intel* processor-based industrial compute and networking hardware from Kontron to streamline the path to workload consolidated system designs.

"Our primary goal is a lower total cost of ownership (TCO)," states Kim Hartman, VP of Marketing at TenAsys. "From day one we've partnered with Intel to take advantage of the inherent efficiencies of general-purpose hardware," which tends to be less costly than specialized systems such as programmable logic controllers (PLCs).

But that is not to say today's "general-purpose hardware" is rudimentary. Ricky Watts, Senior Director of Industrial Solutions for the Federal and Industrial Business at Intel, explains that his company has exposed "a very rich set of tools and capabilities at the platform level and a door within that environment through virtualization."

## Extending Workload Consolidation's Cost Savings Beyond the System

The "door" Watts refers to means the advantages of workload consolidated systems can be extended beyond a local system and across the entire infrastructure. At the network level, this is represented by a migration from the slew of proprietary communications protocols and interfaces one finds in industrial environments today to tomorrow's converged networks based on standard Ethernet.

"The entire sector is migrating to shared, open standards," explains Hartman. "That's why our INtime real-time platform incorporates an Ethernet Time-Sensitive Networking (TSN) implementation." The combined technology stack leverages Intel Time Coordinated Computing (Intel TCC) to synchronize and send real-time traffic over standard Ethernet networks while ensuring critical data packets are delivered with minimal delay and jitter.

While the TSN network standards support a variety of protocols and quality of service (QoS), the fact that this type of network interoperability can be realized using standard Industrial Ethernet means that the convergence and homogenization of physical layer connectivity will drive down costs even further.

## Sharing the Wire While Meeting SLAs

Workload consolidation will also lead to significant performance improvements. Different functions running on a consolidated system can utilize shared platform resources for tighter coupling, leading to lower latency and communication overhead. This is particularly advantageous compared to disaggregated implementations where workloads are distributed across separate physical systems and networks. Redundant enterprise and control network implementations suffer from inefficiencies and performance bottlenecks that are addressed through workload consolidation.

At the same time, resources can be reserved for specific workloads in a consolidated system to guarantee consistent performance and meet stringent Service Level Agreements (SLAs). A technique known as “CPU pinning,” for instance, dedicates a processor core to a single task, ensuring uninterrupted performance.

“We can pin CPUs, cores, or threads to certain workloads to ensure a given workload uses a specific core and nothing else touches that core,” says Watts. “Then we have technologies such as TSN that allow us to further the service assurance that applications can use to ensure they meet their SLAs.”

The capabilities of the latest Intel Atom and Core processors are taking these concepts to the next level. For instance, Intel Core processors feature a hybrid architecture with a mix of performance- and efficiency-optimized cores. Cores can be assigned according to workload requirements, ensuring critical tasks receive the necessary processing power while less demanding workloads operate efficiently without compromising overall system performance.

Even more exciting possibilities lie ahead. “Throughout our long partnership with Intel, we've enjoyed early access to next-generation technology," notes Hartman. “We continue to be on the forefront of driving forward workload consolidation initiatives on PC platforms and foresee ongoing opportunities with complimentary workload areas like AI.”

*"Manufacturers want to modernize, but they want to do it with the people they trust so they can get comfortable building a value proposition around these open and integrated systems, where they can reduce costs and plug-and-play everything from containers to AI without additional risk."*

*— Ricky Watts, Senior Director of Industrial Solutions for the Federal and Industrial Business at Intel*

## Safety and Security Coupled with Rapid Innovation

In industrial systems, safety and security are paramount. To address these concerns, TenAsys solutions isolate workloads in hardware partitions, preventing interference between tasks. This ensures that, even in a consolidated environment, each function operates independently, safeguarding the system’s integrity and limiting the impact of potential security breaches.

This concept can be extended through virtualization, which enables multiple operating systems to run on the same hardware. The approach facilitates the consolidation of workloads with diverse operating systems, such as a real-time operating system (RTOS), Linux, and Microsoft* Windows.

Plus, by enabling flexible combinations of workloads in virtualized environments, developers can implement modern, cloud-native development workflows. This streamlines the development process, leading to faster engineering cycles and enabling rapid innovation for robust, secure, and high-performance industrial systems.

## Embracing the Future of Industrial Efficiency

Workload consolidation presents a compelling value proposition for the future. By offering significant cost savings, enhanced performance, and improved safety and security, this technology paves the way for more efficient and reliable operations across various industries.

“At the end of the day, it’s very clear that technologists do technology and manufacturers build,” Watts says. “Manufacturers want to modernize, but they want to do it with the people they trust so they can get comfortable building a value proposition around these open and integrated systems, where they can reduce costs and plug-and-play everything from containers to AI without additional risk.”

As TenAsys and Intel continue to collaborate and innovate in this domain, we can expect even more advancements that unlock the vast potential of workload consolidation and shape the industrial automation systems of tomorrow.

# Future-Proofing Industrial Equipment with Workload Consolidation

BY BRANDON LEWIS, EMBEDDED TECHNOLOGY INDUSTRY ANALYST

Industrial organizations are facing a dilemma: Innovation is moving at an ever-faster pace, but industrial equipment has lifecycles measured in years or even decades. How can businesses ensure that today's investments will support tomorrow's technologies?

Workload consolidation has emerged as a strategic solution to this question. By migrating disparate specialized systems onto a single standards-based platform, industrial organizations gain a powerful tool for future-proofing their operations.

Intel*, TenAsys®, industrial PC suppliers like Kontron, and the middleware ecosystem are partnering to assemble workload consolidation building blocks that allow industrial organizations to capitalize on the benefits of workload consolidation today. Together, they are developing a unique value proposition that enables support for both real-time and non-real-time workloads on the same hardware platform, which opens a world of technical and business possibilities for next-generation manufacturing organizations.

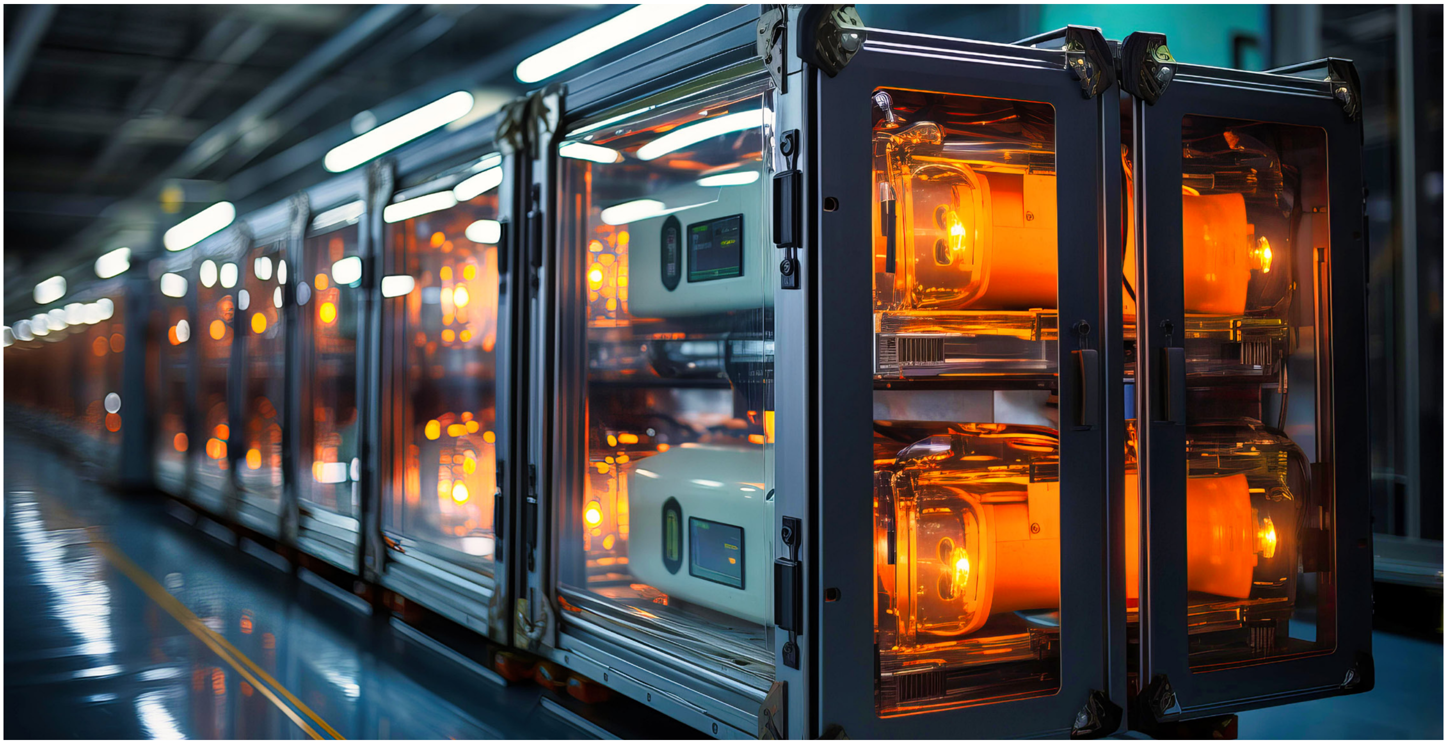
"Guaranteeing real-time determinism is one of the hardest challenges in system consolidation," says Kim Hartman, VP of Marketing at TenAsys. "We were the first to reach this landmark, and we continue to push the boundaries of innovation through our partnership with Intel."

## Preserving Legacy Investments

Intel Virtualization Technology is one of the key enablers of this approach. This technology abstracts away underlying hardware complexities, which "allows legacy applications to run seamlessly on modern hardware," explains Ricky Watts, Senior Director of Industrial Solutions for the Federal and Industrial Business at Intel. "This effectively extends their lifespans and preserves the value of existing intellectual property."

TenAsys integrates this technology to provide a turnkey solution. "We've used our INtime® real-time operating system to build a platform that streamlines the process," says Hartman. "Our mission is to simplify IP migration, minimize the costs, and ensure that newly consolidated systems maintain extensibility for the future."

Contrast this to traditional IP migration approaches, which often require significant code modifications or complete rewrites when migrating applications to new hardware platforms. By avoiding this step, workload consolidation ensures that IP can be reused without ongoing expenditures.



## Enabling Granular Upgrades

When it comes time to update a system, workload consolidation offers another advantage: granular software modification. Traditionally, industrial equipment could only be updated by taking the entire system offline, leading to potential production disruptions. Today, virtualized environments allow individual software components to be updated in isolation, without impacting the entire system.

By updating components individually, businesses can minimize downtime and ensure operational continuity. Granular upgrades simplify the scheduling of maintenance, making it easier to roll out updates and patches quickly. Businesses can adapt to changing requirements and technological advancements at their own pace.

## Streamlining Development: A Unified Platform for Efficiency

Workload consolidation also simplifies the development process. Traditionally, each industrial system might have its own development environments and toolchains. This fragmented approach can lead to inefficiencies, increased complexity, and potential errors. By bringing workloads together on a unified platform, developers can rely on a single set of tools. This allows them to focus on delivering value-added features and facilitates collaboration and knowledge sharing among team members. The result is a faster time-to-market and a competitive edge in delivering meaningful innovation.

***"At TenAsys®, we've made it a priority to support diverse workloads and real-time operating system requirements in our toolsets."***

*— Kim Hartman, VP of Marketing at TenAsys*

This allows our platform to accommodate the needs of various development projects, simplifying complex scenarios, and enhancing developer efficiency."

## Unlocking New Service Opportunities

Bringing multiple systems onto a single platform also opens doors to a wide range of service offerings. The streamlined development and management that comes with workload consolidation enables equipment manufacturers and service providers to deliver a more integrated and valuable package to their customers. For example, OEMs and ODMs can now offer comprehensive solutions encompassing various aspects of the software lifecycle, from initial development to deployment and ongoing maintenance.

The potential for these services is enhanced by the collaboration between TenAsys and Intel with partners like Kontron, Real Time Systems, and Straton. Together, TenAsys and Intel have created an ecosystem that ensures businesses have access to the necessary expertise and resources throughout the development and deployment process.

"We're building what you would regard as a digitalization; We're collectively working together to create a SKU or a way it's going to be done," Watts explains. "So we validate and test it with the applications on this piece of software, in this piece of hardware, and that's how you're going to get it."

"But we're doing it in a way that reduces a lot of the risks because Kontron will stand behind that and say, 'If you run it in this configuration, we've tested it and validated it, and you can go off and run your applications and services,' " Watts adds. "It's a transition to what I would call more plug-and-play architecture."

In the rapidly evolving technological landscape, workload consolidation empowers businesses to embrace change with confidence, ensuring the longevity and adaptability of their systems. By adopting this strategic approach, businesses can not only preserve their valuable investments but also unlock new opportunities for growth and innovation in the industrial and embedded systems domain.

# Time-Sensitive Networking: The Foundation of Real-Time Network Convergence

BY BRANDON LEWIS, EMBEDDED TECHNOLOGY INDUSTRY ANALYST

Software-defined manufacturing (SDM) represents one of the final stages of complete IT/OT convergence by connecting enterprise cloud and data center services to industrial edge sensors and controllers. With end-to-end infrastructure in place and multi-function, converged infrastructure platforms operating at or near endpoints, workloads can be orchestrated from edge to cloud with increased efficiency and reduced effort as one would find in a data center.

SDM is the realization of Industry 4.0, where cyber-physical systems rely on real-time data to operate with various levels of autonomy in pursuit of never-before-experienced levels of uptime, productivity, and cost savings. But, until recently, SDM was little more than a concept because of the separate networking and business requirements of IT and OT domains that prevented converged networks from unifying the two classes of systems. Time-Sensitive Networking (TSN) changes all of that.

## Enabling Time-Sensitive Networking for All

TSN is a set of IEEE 802.1 standards that support time-synchronized packet transport over the type of deterministic networks you'd find in a factory. By enabling accurate timing, traffic scheduling, and resource-allocation across a real-time network, TSN serves as the connective tissue required to make concepts like SDM a reality.

TSN standards are based on Ethernet, but at the same time provide an ultra-reliable, low-latency connectivity transport that supports multiple traffic classes and serves as a highly scalable, interoperable networking foundation for Industry 4.0. It allows IoT operators to seamlessly integrate cyber-physical systems, IoT devices, and cloud services. More importantly, it helps them manage all this as part of a single, coherent, virtualization-ready infrastructure (Figure 1).

Of course, the standards are still evolving and implementing a TSN network requires much more configuration than simply plugging in an Ethernet cable. Now, a collaboration between industry leaders, Intel*, TenAsys®, and Kontron is yielding TSN-enabled hardware and software stacks that abstract the complexity of converged real-time Ethernet networks, support the consolidation of different mixed-criticality workloads onto a single edge computing platform, and put SDM firmly within reach.

"There are a number of things in the TSN standards that need to be implemented to make the whole thing work, but there is a shortlist of people in the world who know how to do that right now," says Kim Hartman, VP of Sales & Marketing at TenAsys, developers of the first TSN real-time operating system (RTOS). "By nature of integrating TSN into our stack, we're doing the heavy lifting and providing something that just works out-of-the-box. It's something a developer can pick up and run with."

"This is why we have interest and are taking a lead position in TSN — to enable an RTOS to have TSN services," Hartman continues. "This is democratizing so that anybody who has an interest in SDM, for instance, can come in and pick up the INtime® RTOS and run with it. They can keep their head in the solution space instead of inside TSN," Hartman says.

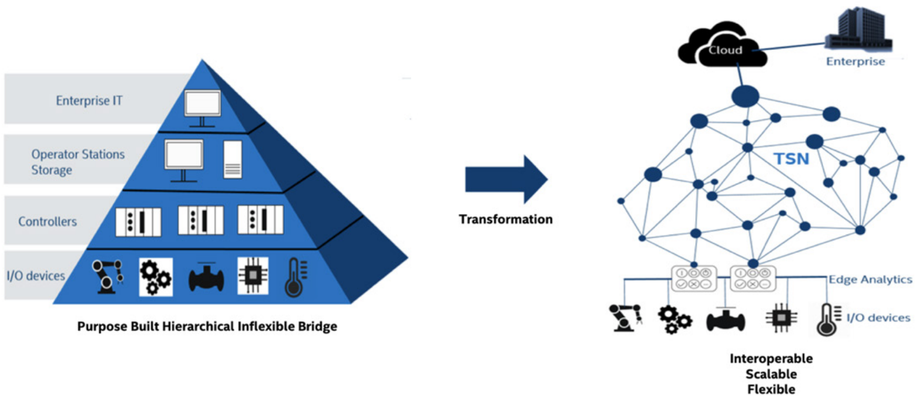



*Figure 1. With TSN, hierarchical networks can be transformed into flexible networks that integrate the enterprise and edge in a highly scalable manner.*

## Time Synchronization for Software-Defined Manufacturing

As automation technology continues to advance, modern systems rely more on software than dedicated, proprietary hardware. With TSN-enabled SDM and an RTOS like INtime, operators can centrally manage their entire infrastructure using software workloads and commands that can be deployed anywhere on the network at any time.

For example, consider the TenAsys TSN demonstrator system (Figure 2). Such a system represents an application like an automated visual inspection system, which depends on low-latency communication to ensure production line determinism. A stepper motor driving the control application needs to be on the factory floor where it is being used, but the PLC controlling the motor can be an edge appliance located anywhere on a TSN-based network.

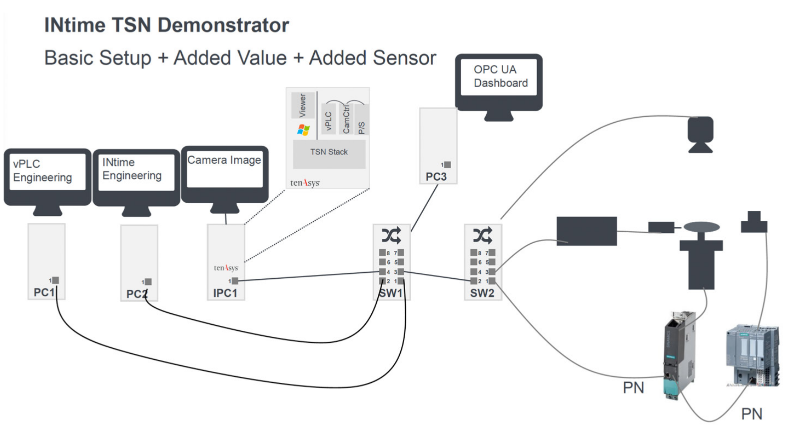



*Figure 2. This diagram shows how Time-Sensitive Networking (TSN) technology enables the distributed deployment of control functions at remote points on a network. (Source: FISW Steuerungstechnik GmbH)*

In addition, a camera—independent of the motor and PLC—can monitor the system and the work the motor is performing. Data from the camera can be streamed to the cloud or enterprise for AI processing, and the analysis can then be passed back down to the PLC to improve operations, all without impacting PLC communications latency.

This is just a representative example. The applications with TSN are endless, offering incredible deployment flexibility that is highly scalable. More sophisticated use cases such as collaborative robots, augmented reality for maintenance, and automated quality control become possible at a broader scale with SDM over TSN.

## Simplifying Network Convergence for a Broad Range of Applications

TSN fundamentally changes how industrial applications can be deployed. Rather than adopting specialized, often proprietary edge hardware, general-purpose multicore control platforms can be selected and deployed independently. This enables manufacturers to optimize their equipment selection and also deploy that equipment anywhere across their infrastructure—regardless of proximity to sensors and actuators.

For example, in a TSN-enabled SDM deployment, all PLCs can be virtualized (vPLCs), consolidated, and co-located off the factory floor to protect from environmental factors such as vibration and heat. It can also improve security by positioning critical systems behind locked doors and simplify management and maintenance by concentrating devices in a single room instead of dispersed across a campus.

Note that TSN achieves this by simplifying the network rather than adding additional layers of complexity. TSN-enabled network components address many of the challenges associated with deploying and managing real-time distributed networks. This reduces implementation complexity and the need for specialized domain expertise, thereby reducing total cost of ownership and time to market.

## How Intel*, TenAys®, and Kontron Hook Mixed-QoS TSN Workloads to Hardware

A software-defined environment requires precise time for resource coordination and management to account for required application latencies. Intel Time Coordinated Computing (Intel TCC) is the combination of modern software and real-time capabilities, an emerging technology on select Intel platforms that provides optimizations and features that make precision timing available to the management of software, cache memory, I/O, and other local resources. The TenAsys INtime RTOS utilizes TCC capabilities to synchronize its TSN stack and ensure the determinism that is required to interface real-time workloads with TSN networks.

Intel TCC and the INtime RTOS can be combined with [TSN-based Ethernet switches] such as the [Kontron KSwitch D10 MMT Series] to guarantee low latency, jitter, and quality of service (QoS) for real-time manufacturing use cases. From here, manufacturers just need to "connect" real-time systems and TSN takes care of the rest — even when the network carries "mixed" traffic (i.e., control traffic and non-real-time data).

As Greg Schlechter, Senior Director of Technology Strategy at Intel, explains, the TSN-Intel TCC-INtime RTOS stack provides "a predetermined channel to speak over an enterprise network that is also deterministic and reliable."

"Sharing control information or data that is part of a control loop between compute systems is possible," Schlechter continues. "And now you're heading towards something that is truly a distributed network of [synchronized] compute controllers."

## The Future of Manufacturing is Deterministic and Software-Defined

Traditionally, manufacturing systems have been proprietary and OEMs would have to buy an entire networked system of systems from a single vendor. Because these solutions are typically based on proprietary protocols, their systems are rendered incompatible with other similar systems available from other vendors.

Now, TSN makes it possible to select the most appropriate components for a particular application from a diversity of vendors adhering to the converged TSN standards. OEMs can work with off-the-shelf components rather than invest in full-custom solutions. It also increases OEMs' access to a wide variety of tools and support across the ecosystem. In short, the new approach to manufacturing makes it easier for OEMs to benefit from advances in automation and the democratization of technology and standards.

TSN promises to bring a new level of precision and real-time responsiveness to manufacturing. It has the potential to democratize access to advanced industrial automation solutions, enabling manufacturers to make their long-awaited appearance on the digital transformation stage.

# The Evolution of Real-Time Computing, Time-Sensitive Networking and More

INTERVIEW WITH ***CHRISTOPHER MAIN*, *CTO AND FOUNDER OF TENASYS® CORP.***

***Embedded engineering has changed a lot since TenAsys® was founded more than 25 years ago now. How have you seen the change in the industry, and what's the same and what's different?***

**CHRISTOPHER MAIN (MAIN):** Well, at that time, we were emerging from a time where your control systems were custom-designed hardware and software, and people were beginning to adopt the PC and the Microsoft* Windows operating system, primarily because of the wealth of software available on Windows, and PCs were becoming ubiquitous. And Windows NT 4.0 was finally deemed to be reliable enough to support an application that might run for more than a day. This was the time of single-core CPUs, so it was a bit of magic where we were able to run our real-time operating system at the same time as Windows was running on this PC.

And we were using the real-time operating system to provide control capabilities, so somebody could build, for example, a PLC with a programmable front end and then a real-time engine on the back end to do the control. Prior to that, we used to talk about the two-box solution where you'd have a general-purpose PC with a nice interface and something running like QNX for example, or iRMX from Intel* on custom hardware to do the control. And the idea was, we can do this on one PC and allow you to do what you need to do and throw away one of your computers and [simplify development].

***So, this was like virtualization and workload consolidation before those were things?***

**MAIN:** Absolutely. You look at some of Intel's presentations or other people's presentations now, they have the right slides which we had 25 years ago. Obviously, some things have changed since then.

There have been developments in the meantime such as multi-core CPUs. That was a really interesting one. For example, we were at an exhibition that Intel had invited us to. We had an early application showing we could run our real-time operating system on one core and Windows on another core.

And they were touting this multi-core, two-core capability and it was interesting that a senior scientist from one of those big automation companies came up to us and asked the Intel people: "Does that mean I can run one operating system on one core and a different one on another one?" And they said, "Come around the corner and meet our friends from TenAsys®." And we were doing exactly that. Suddenly people were able to understand what we were doing after four years in the market. So how do you do two things with one core?

Oh, you've got two cores. Oh, well, it's obvious. So, there we go.

***Since then, a lot has changed. I don't even know if you can get a single-core CPU from Intel anymore.***

**MAIN:** I was going to say, there's been other developments. Obviously, it's not just the multi-core. Intel introduced hypervisor technology, which we were really excited about. We thought we could really do something with this and did it for a while. In the meantime, there's other people who've concentrated on that technology and we've backed away a little bit. But we're now working with those partners to take advantage of that technology.

Because what it does is it makes it easier for you to consolidate not just two workloads, but multiple workloads and isolate those workloads, not just for performance, but for security and reliability as well. The development of the hypervisor has been really important to this space. Many spaces, but it's just coming to this space too.

***Here we are, decades later, and TenAsys is still leading-edge. How have you been able to evolve with the dynamic requirements of your customers over the last 20 plus years?***

**MAIN:** Well, part of it is looking at how the landscape was changing. I mean, there was a big change in the way I/O was driven, which we can go into. More important, it's about listening to our customers, and what they want to do.

Some of our customers have, you know, quite forward-looking things. We're very interested in keeping up to date with where they think they need to go and helping them get there or explaining why they need to do a different thing. Trying to provide core technology that allows them to do what they need to do.

For example, this I/O shift I was just referring to: In the old days, you had a custom controller board plugged into your PC with specialist cables connected to your I/O device for vast prices. Not very many manufacturers were able to participate in that. They gradually shifted their technology to standard Ethernet. We were able to provide Ethernet software to allow people to connect to whatever the devices on the other end were, whether it was technologies like EtherCAT or PROFINET and so on. We were able to provide some basic software to allow people to develop those stacks on top in a way that it provided the appropriate performance. One of the significant things is being very deterministic when a packet is transmitted to these devices.

And we made some modifications to the Ethernet software to enable it to be incredibly precise. And that was very popular as these Ethernet-based technologies for I/O took off. We had worked with some partners who based their I/O stacks on INtime® and made this Ethernet technology available to individual customers who were able to implement their own things without having to buy third-party solutions. Particularly in the EtherCAT area, that's very easy.

We were ready to look for the next shift that was going to happen in that area. It became clear about five years ago that it was going to be TSN.

***With Time-Sensitive Networking (TSN) standards, the promise is immense. You mentioned EtherCAT, PROFIBUS, all the other deterministic flavors of industrial Ethernet. The promise of TSN is we can bring those all under one roof and from the network perspective and accommodate them all. Is that correct?***

**MAIN:** There are two things happening. One is, yes, all these different standards are proprietary, and some manufacturers decided to use the TSN standards to say: "look, we're now using a standard, standard. It's not proprietary."

And they're using TSN like they use their proprietary standard to provide deterministic I/O access and so on. But that's all it is. It's standardized access to their I/O.

They don't get to share the network, at least not very easily, at least at this time. Whereas where we see TSN going is more, it's enabling converged networking where multiple applications are able to share the same network, not just the same platform. Or multiple applications or multiple controllers are able to share access to multiple devices across the same network.

TSN allows you to do that because you can configure multiple applications to use the same network. They have their own bandwidth requirements and timing restrictions and so on. And that can all be designed into the configuration of a TSN enabled network.

***Besides getting locked into a specific vendor's flavor of Ethernet, why would anybody care about TSN? You've proceeded to answer, "They'd be interested in TSN because of this converged network." But the next question is, "Why does anybody care about having a converged network or the ability to have these distributed applications?" And what is this going to enable for us in the future?***

**MAIN:** Well, converged networking. Converged networking is the stepping stone into some big initiatives in the industry. One of which is the further development of Industry 4.0 or "smart manufacturing." The ability to reconfigure your network in software as opposed to sending your technician down to rewire your factory is a big plus, in my opinion. Tilting everything towards software instead of continuously changing your hardware and changing the wires and so on. And the even more exciting one is the step towards what's called software-defined manufacturing.

This is an initiative that came out of software-defined networking, but it's being applied to the manufacturing sector. It has to do with the design, configuration and integration of a complete manufacturing facility, a factory, connected all the way back to the IT side of things as well, where you can design and simulate your whole factory first and then turn that into your real factory just by applying that configuration to your real hardware. That has huge implications for the way that factories operate and run and how efficient they can be and so on and so forth.

***How does the TenAsys portfolio come into play here? Obviously, you have the INtime®, real-time operating system and complimentary tools and infrastructure to support that RTOS, but what does real-time software in general have to do with TSN?***

**MAIN:** Well, the applications that you're supporting on the TSN network will involve some control, and that requires a real-time operating system at the controller end in order to be deterministic, service the inputs, provide the outputs as designed and not to vary. And that's what your real-time operating system is for. If your real-time operating system is going to operate over a TSN network, we have to provide the fundamental infrastructure to allow you to interface to that network, which means providing the scheduling, the configuration and synchronization that's required in order to do that.

***When you start talking about the combination of TSN and workload consolidation, I mean, you have a couple of significant building blocks that are fundamental to the fabric of who TenAsys is that are stepping stones towards this software-defined manufacturing future. Would you agree with that statement?***

**MAIN:** Imagine today a corner of a factory that has eight controllers connected to 40 motors, which are physically connected to eight separate machines. If you look into the future there, you can imagine a server platform with eight virtual PLCs connected through a converged network to your 40 motors in different combinations, depending on what it is you want to manufacture or what it is you want these machines to do. That's the vision and that's the way forward that people are talking about in this market.

***So, you've got these pillars. Obviously, the next step is to take these pillars from being abstract concepts and start putting them into actual working proofs of concept. And I know that you've done that. Can you explain a little bit about some of the demos and reference designs that you've been working on and how they capture some of the capabilities of TSN?***

**MAIN:** For example, at Embedded World 2024 we developed a concept demonstration to illustrate our ideas about TSN. It shows three things.

One is that we can support multiple applications on a converged network. Secondly, we're showing an existing application based on PROFINET showing that you can adapt it fairly simply in order to operate over a TSN compared to its original OT connectivity without too much effort. And this is going to be important in the adoption of TSN in the market. Thirdly, it illustrates our concept of how the TSN interface is presented to the developer that we're hiding all the complexity and just revealing the resources that are required by the developer in such a way that they can pick them up and use them in order to realize their application.

***There's no TSN stack or TSN demo out there that's built on one vendor's component. What are the technology partner components in there?***

**MAIN:** Most of this development we've been doing is in association with the ISW at the University of Stuttgart. They have a group that's very focused on TSN in automation. And has been driving some of the adoption of TSN and so on.

They helped us develop the software model that we're presenting here. Very knowledgeable people, who have a great ear to the ground in the industry. They are a very valuable partner.

The key component in any TSN implementation is PTP, the Precision Time Protocol, which synchronizes everything in a TSN network. And when I say everything, I mean absolutely everything.

Everything connected to a wire has to be synchronized within less than a microsecond in order for TSN to work at all. And we, rather than develop our own PTP solution, work with a partner called TSEP, a German company who has been providing PTP solutions for a long time. They have a lot of expertise we've been able to draw on. Then we've got some hardware partners as well in our demonstration.

Kontron is known for providing TSN-enabled hardware components. We're using some of their switches in this demonstration. And of course, Intel in their silicon has provided TSN features in their network controllers that we're using.

And, within the CPUs are features from the TCC initiative, allowing the CPU to behave in a real-time deterministic way all the time which is essential in the sort of application that we're talking about.

Intel Time Coordinated Computing (Intel TCC) does a really good job of providing that hardware enablement and then also software tools that higher level technologies like INtime can take advantage of. We can then really abstract away all the complexity of these underlying synchronization between all of these various endpoints, etc. Developers can then just focus on application development, which is really great towards, as you said, enabling adoption of TSN in the market.

***There were four or five different suppliers in addition to TenAsys. Do you think with that stack, with all that infrastructure, that we are at a point where in the not-too-distant future we can start to realize some of the benefits and advantages of software-defined manufacturing?***

**MAIN:** Yes, I think that stack is certainly providing a big step forward on the production side of software-defined manufacturing. There are also other components required on the simulation configuration side, which are also present today, and we have partners that we work with who are active in that area as well. So yes, I think there's a good ecosystem developing that's going to be able to bring this to fruition.

***Given the fact that we've got all of this at our disposal now, what's the future? What's next for TenAsys and its partners in TSN?***

**MAIN:** Well, we've come a long way. We've managed to produce a proof-of-concept demonstration. We need to continue to work with our customers and partners as these ideas continue to be adopted and we need to understand where the real use cases are going to be.

There's a couple of obvious ones emerging at the moment. For example, the OPC Unified Architecture initiative has got some very well-defined uses of TSN within it, but that's just one application. There's going to be many more.

We're going to continue to follow our customers' requirements and [leverage] our partners' knowledge and experience in order that we can continue to lead this initiative and provide effective solutions to the market.

*Listen to the full interview with **Main** and industry analyst **Brandon Lewis** here.*

# Abstracting Configuration Complexity of Time-Sensitive Networking to Accelerate Mass Adoption

BY CHRISTOPHER MAIN, CTO AND FOUNDER OF TENASYS® CORP., AND FLORIAN FRICK, GROUP LEADER OF REAL-TIME COMMUNICATION AND CONTROL HARDWARE, INSTITUTE FOR CONTROL ENGINEERING OF MACHINE TOOLS AND MANUFACTURING UNITS (ISW), UNIVERSITY OF STUTTGART

Time-Sensitive Networking (TSN) enhances standard Ethernet with determinism and synchronization, making it suitable for use across converged infrastructure networks. TSN operates in Layer 2 of the OSI model, making it a data link technology that can be adapted for use with different network configurations and higher-level protocols. But as TSN continues to evolve, organizations looking to capitalize on its benefits today must enlist technical experts who understand its nuances and how to deploy it for specific use case requirements.

Most users are only concerned that TSN delivers the features necessary to create, deploy, and manage new deterministic applications and services. While highly specialized experts can accomplish this, needing one just to configure TSN endpoints and applications is a barrier to adoption. For TSN to reach critical mass, industry needs an abstraction layer that simplifies the configuration of time-sensitive applications and endpoints to make TSN accessible to all.

This paper considers ways to abstract the complexity of TSN applications and endpoints through a single pane of glass — the TenAsys® TSN RTOS, INtime®. From there, the potential of TSN in a software-defined manufacturing facility comprised of workload-consolidated virtual PLCs (vPLCs) is reviewed. The paper concludes by demonstrating how today's complex mix of industrial hardware and networking technologies can be consolidated and unified to help industry realize the benefits of true IT/OT convergence.

The IEEE's efforts to converge operational endpoints and IT infrastructure over a universal time-sensitive Ethernet standard — Time-Sensitive Networking — are now more than 10 years old. TSN improves network determinism, synchronization, and reliability; reduces costs; and consolidates the wide selection of Ethernet-based fieldbus networks for automation companies. But, to date, TSN has only been adopted by a few organizations as a spot replacement for legacy fieldbuses — never mind as industry's answer for ubiquitous converged networking.

Since the IEEE TSN task group formed, multiple extensions to the base TSN data link standards have emerged that make it suitable for use with higher layer protocols like PROFINET, CC-Link IE, OPC UA FX, and others. On one hand, the new flavors are a testament to TSN's viability as a next-generation, real-time converged networking solution. On the other, they cause confusion, primarily because the TSN standard allows higher layer protocols to dictate how lower layer protocols are configured and operate.

Put simply, TSN configuration requirements can vary from protocol to protocol and use case to use case, so implementing them requires an expert — hardly the single, unifying technology that was promised.

For TSN to achieve the critical mass industry has been waiting on for more than a decade, users must be able to access it without understanding its nuances; they must be empowered to leverage TSN's determinism, data transparency, cost, and other enabling characteristics in their applications without being TSN experts themselves. With it, today's OT environments will be transformed from rigid, hardware-centric environments into dynamic, software-defined ecosystems driven by deterministic virtual PLCs (vPLCs) and capable of IT/OT convergence.

To get there, endpoint and application developers working with TSN need an IT/OT network abstraction layer like what can be realized with the TenAsys INTime RTOS.

## Abstracting Network Complexity to Scale Time-Sensitive Networks

Because there's currently no unified method for configuring TSN endpoints, they must be configured manually. Today, this means you need a specialist to build a TSN endpoint. A specialist is also required just to create TSN-aware applications because, of course, these applications must be developed with the subtleties of the underlying network in mind.

TSN-enabled hardware that could reduce some of the endpoint configuration and application development complexity is slowly reaching the market in the form of infrastructure like switches and controllers.

For example, the Intel* Ethernet Controller i225 supports TSN features such as time synchronization (IEEE 802.1AS), time-based and credit-based shapers (IEEE 802.1Qbv and Qav), frame preemption (Qbu), and precision streaming. But even with a controller like the i225, developers must tune endpoints to support the deterministic requirements of TSN applications.

This immediately narrows the field of available development solutions; for example, configuring IT-centric operating systems like Linux to support real-time TSN applications requires complex workarounds that should be avoided if at all possible.

Starting with building blocks that were developed from the ground up for real-time performance is the preferred approach.

For instance, the built-in communication system of TenAsys' INtime RTOS was designed to manage deterministic traffic flows and can be utilized out of the box. INtime supports TSN protocol stacks; includes a High-Performance Ethernet (HPE) interface for most real-time Ethernet protocols; contains drivers for Ethernet controllers (including the Intel i210, i225, and others); and allows for the creation of explicitly partitioned operating environments with dedicated resources that ease real-time application development on multicore processors.

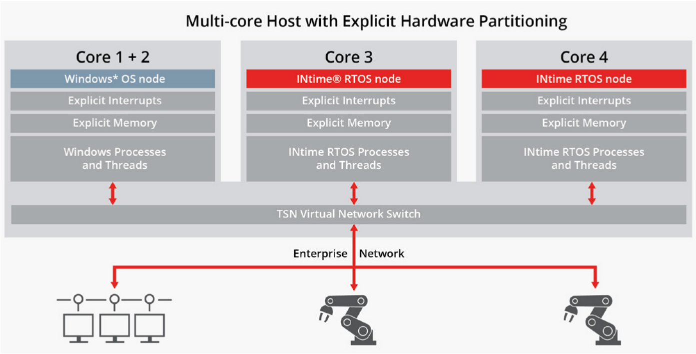



*Figure 1*.*The TenAsys® INtime® RTOS reduces the complexity of TSN deployments by partitioning applications and workloads into isolated environments on multicore processors. This allows the underlying network and driver configurations to be abstracted from application developers.*

Depicted in Figure 1, the embedded virtualization capabilities of INtime software allow it to allocate compute, memory, and communications resources to specific processes. For TSN applications, this means the RTOS can guarantee different levels of determinism to different streams or classes of multi-protocol traffic. In other words, INtime can be configured as a "virtual network switch" that allocates virtual network resources as needed to different connections interfacing with an application — even across multiple virtual endpoints on multiple nodes.

Given that TSN is, by definition, a technology that involves multiple nodes, the ability to function as a virtual switch is critical. When paired with the RTOS's support for TSN sub-standards regarding traffic shaping, configuration, reliability, and time synchronization (including the Precision Time Protocol (PTP) often used to provide unified timing for devices on a TSN network), it permits applications running in an INtime partition to use external timing sources as a reference for scheduling local real-time processes. From there, real-time tasks can be orchestrated between workloads running in separate partitions thanks to INtime's asymmetric multiprocessing (AMP) architecture and global objects-based (GOBS-based) inter-process communications (IPC) mechanisms.

From a development perspective, INtime serves as an abstraction layer for workloads running inside its partitions. When viewed as an endpoint manager, this means INtime can translate specific application requirements into hardware and driver configurations. As a result, the average developer doesn't need to understand all the intricacies of TSN components, traffic queues, timing offsets, etc. to make use of the networking standard. Instead, INtime's application development tools and utilities function as a network configuration interface that allows workloads running on INtime to be implemented at the application layer or directly on top of the TSN network below — whatever the use case requires.

## Multi-protocol TSN Accelerated Software-Defined Manufacturing

The flexibility and usability of a TSN enablement platform like INtime transforms the growing diversity of TSN-powered application-layer protocols from an interoperability challenge into an opportunity for deployment optimization. An example of the opportunity is apparent in automation environments, which are increasingly software-defined.

Rather than the current practice of deploying a discrete, dedicated hardware appliance for every control function on a factory floor, software-defined manufacturing environments like those described by the SDM4FZI project will depend heavily on virtualized control solutions like vPLCs. In parallel, software like the INtime Distributed RTOS will allow vPLCs and other virtualized control functions to be implemented as workloads that run agnostically inside explicit partitions with dedicated resources (Figure 2).

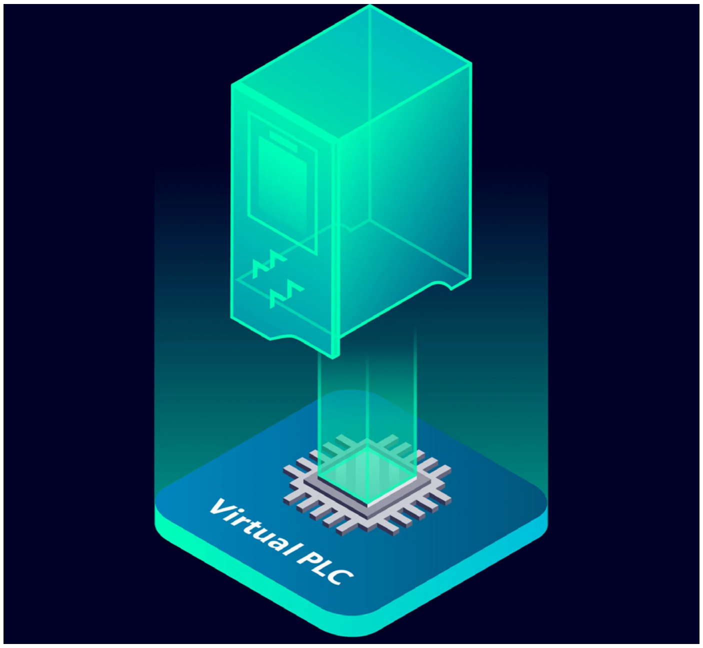



Figure 2. *Virtual PLCs (vPLCs) like the Siemens* SIMATIC S7-1500 can be implemented as workloads on partitioned multicore processors, paving the way for industrial PCs to operate as multi-function automation controllers. (Source: Siemens Blog)*

The primary advantage of this approach is that many INtime vPLC partitions can run side-by-side on a multicore industrial PC. So instead of deploying or managing tens, hundreds, or thousands of discrete hardware controllers, plant operators can consolidate all their real-time control tasks onto a few high-performance multi-function automation controllers.

In the not-so-distant future, TSN links will connect these multi-function controllers to each other and to devices operating at the field level, such as robotic arms, actuators, and industrial sensors. Applications distributed over multiple logical control nodes will be synchronized, orchestrated, and managed by the TSN-aware INtime Distributed RTOS, ensuring the end-to-end continuity of real-time jobs and improving factory yields and uptime.

But beyond controller-to-controller and field-to-controller communications, these job-centric workflows can use TSN to deterministically integrate other systems like edge analytics servers or supervisory control and data acquisition (SCADA) systems. The result is incremental progress towards comprehensive IT/OT convergence, where real-time predictive maintenance and autonomous process optimization are suddenly accessible.

Through a single pane of glass, INtime provides the software foundation needed to realize such use cases by supporting multiple TSN traffic types and protocols over a single Ethernet wire (Figure 3). For example, an industrial PC controller running one or more instances of INtime could:

- Synchronously communicate with other distributed, multi-function industrial PC controllers using PTP over TSN
- Have partitioned vPLCs communicate with and control robotic arms, belts, and actuators via PROFINET over TSN
- Link to SCADA servers via CC-Link IE
- Relay operational data to edge analytics servers through OPC UA FX

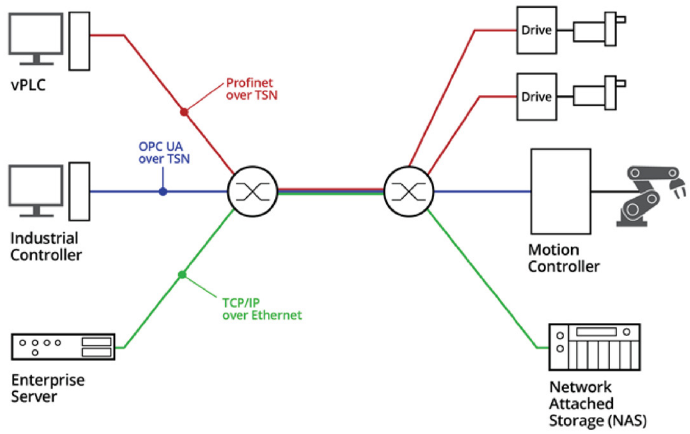



*Figure 3. INtime®'s broad TSN protocol support allows heterogeneous application-layer protocols to converge on the same infrastructure and even in the same application.*

## TenAsys® INtime®: Quick-Start TSN

Like other networking technologies, TSN is an application enabler. By delivering improvements in network determinism, synchronization, interoperability, reliability,and cost, TSN facilitates the creation of new use cases and the enhancement of existing ones in ways the automation industry hasn't experienced in decades. Moreover, it sets the stage for a software-defined future where the OT total cost of ownership (TCO) is reduced dramatically by deploying, managing, and maintaining workloads remotely — all over real-time Ethernet that spans from edge to enterprise.

But without reducing barriers to access, TSN will never become unified and ubiquitous enough to realize the possibilities of true IT/OT convergence.

TenAsys INtime software is a quick-start TSN solution that supports a variety of industrial application protocols, different network configurations, and abstracts the complexity of deploying TSN endpoints. And with an architecture that can scale to support deterministic Wi-Fi, 5G over TSN, and integration with software-defined networking (SDN), it's also prepared for the TSN installations of tomorrow.

# Time-Sensitive Networking: Poised to Transform Industrial IoT

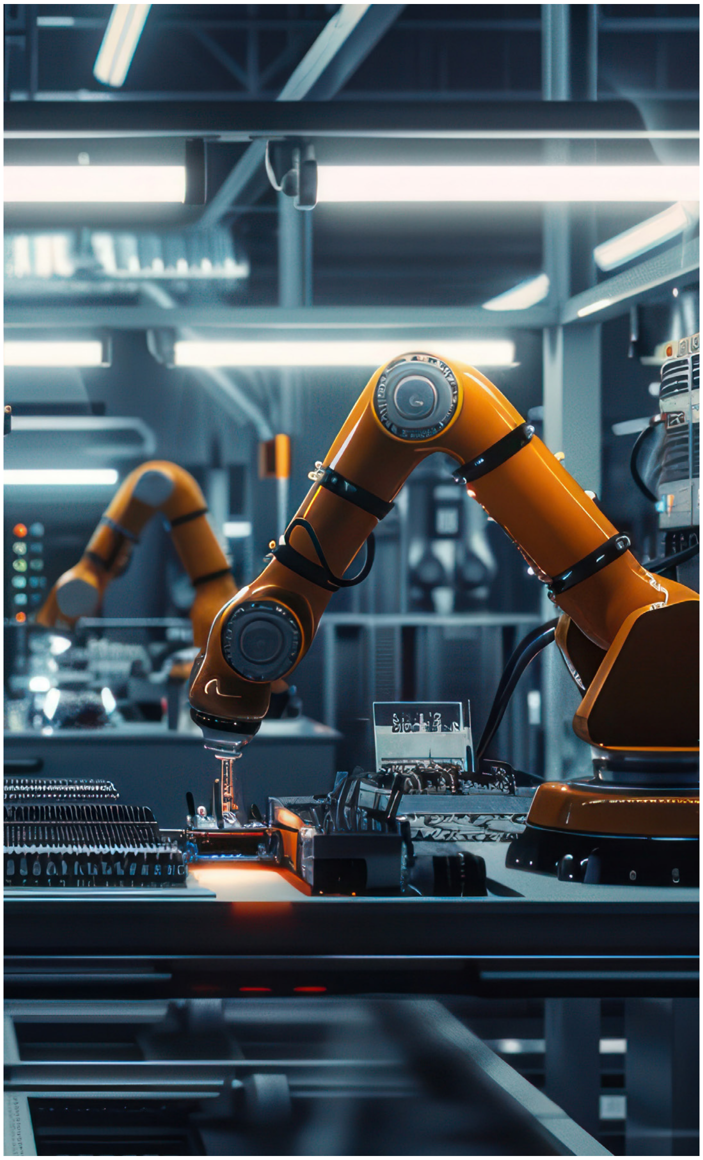
BY BRANDON LEWIS, EMBEDDED TECHNOLOGY INDUSTRY ANALYST

Early IoT proofs of concept were built on architectures that transmitted edge sensor data directly to cloud instances where it could be analyzed for operational insights. But those deployments emphasized data more than long-term outcomes — and data is helpful only if you can respond to it.

The actual value and perceived potential of IoT suffered as a result, and now the exit of Google* and IBM* from the IoT platform business has some wondering whether IoT has failed altogether. It undeniably has not, but the gap between insights and outcomes still exists because of disparate business and technology paradigms that govern the IT and OT sides of IoT infrastructure.

Time-sensitive networking (TSN) is a framework for synchronizing the timing of Ethernet data to flow throughout converged enterprise and operational environments. It enables near real-time decision-making between controller, sensors, and edge devices where outcomes can be realized.With TSN, information and value exchanges can happen overa single, low-latency network that maintains the ability to prioritize different types of traffic.

Now, new capabilities are coming to market to streamline the development, deployment, and configuration of TSN networks. When paired with virtualization-friendly infrastructure, these new solutions empower industrial operators to port workloads across IoT deployments and drive outcomes when, where, and how they need them.



## Standardizing Time-Sensitive Networking for Seamless IoT Integration

TSN is not the first or only deterministic Ethernet technology, but others are largely proprietary and don't provide the openness to move data seamlessly in both directions across an end-to-end IoT network. The key value of TSN is standardization. It replaces proprietary fieldbuses with a converged network that virtualizes the connection between entities on the network and satisfies the ranging requirements of industry IT and OT stakeholders. IEEE's Time-Sensitive Networking Task Group, established in 2012, is working to finalize the set of standards.

"We're more than 10 years in on TSN standards work, but we can't get there until the foundational technology has been defined, implemented, and tested," says Joel Morrissette, Product Manager at embedded software supplier TenAsys® Corporation, a real-time software and service provider.

"What does it mean to configure the network? What does the data structure look like? How do the hardware and software stacks need to be supported? What's the division of duties? How do I access TSN, from an application perspective?"

The good news is that TSN standards-compatible hardware and software that streamline network deployment are finally coming to market. There is now a range of commercially available Ethernet hardware that provides native TSN offloading.

Intel* CPUs provide TCC functionality that enables the software stack to achieve the real-time performance required for TSN with higher precision than non-TSN-enabled CPUs.

For instance, Intel Ethernet products, Intel Atom processors x7000E Series, 13th Gen Intel Core embedded processors, and next-gen Intel Xeon D-1700/2700 processors are all equipped with Intel Time Coordinated Computing (Intel TCC) technology.

"Every node in the network gets the same information and synchronizes down to microseconds, ensuring everybody is in lockstep with respect to time," Morrissette explains. "Because of that coordination, we're able to prioritize traffic and ensure low latency and a high degree of determinism."

## Industrial IoT Steps Forward

Intel TCC provides the hardware features and software tools to ensure applications can meet real-time constraints, and TSN-enabled hardware helps control when and how data packets move through a TSN network.

But taking advantage of these capabilities in deterministic applications like those running on industrial IoT systems still requires a high level of expertise to configure the application and TSN network to meet real-time constraints.

TenAsys INtime* IoT software supplies the missing link. It is a scalable portfolio of TSN- and TCC-compatible deterministic operating system (OS) solutions that can be deployed as either a standalone or distributed RTOS in support of applications that run on multiple nodes. It can even be implemented as a virtualized real-time companion OS to Microsoft* Windows or Linux hosts.

INtime abstracts the complexity of TSN network configuration through a suite of developer APIs. The software supports a variety of communications protocol that eliminate the need to understand different traffic classes and how they're scheduled on the network. Plus, the INtime SDK provides developers with tools, such as a timing analyzer, that can be used to further optimize time-critical applications.

"TenAsys is taking care of the 'how' under the hood so developers can focus on the 'what' and the 'when' as they're developing these applications," Morrissette says.

INtime's native support for TCC features and its API abstraction of underlying TSN networking capabilities are the key to unlocking the true value of IoT in time-critical industrial applications.

Utilizing the native hardware virtualization features of multicore Intel processors, an instance of INtime can be allocated to a dedicated CPU core and run within a full-featured virtualized hardware environment with allocated memory, I/O, and other system resources.

As a result, applications built and deployed on the INtime platform can then be deployed in a distributed real-time OS (DRTOS) environment. This enables portability and flexibility for industrial IoT real-time applications delivering time-critical data capture, analysis, and decision-making at the edge.

## Achieving a True IT/OT Convergence Strategy

Time-sensitive networking technology can unify IT and OT systems to deliver industrial IoT network interoperability and workload portability. With over 10 years of experience in the TSN space and decades as a provider of RTOS technology, TenAsys is uniquely positioned to deliver the technology convergence required to accelerate broad TSN adoption for industrial IoT.

By integrating and abstracting TSN and Intel TCC technologies, INtime can provide developers the tools to manage the complexity of configuring, deploying, and managing converged IT/OT time-sensitive networks. This will pivot the industrial digital transformation from data to information — a key element for delivering the results that will accelerate adoption and amplify the value of IoT at the industrial edge.

*"Every node in the network gets the same information and synchronizes down to microseconds, ensuring everybody is in lockstep with respect to time. Because of that coordination, we're able to prioritize traffic and ensure low latency and a high degree of determinism."*

*— Joel Morrissette, Product Manager at TenAsys*

# Technology Partners

TenAsys® works with partners around the world to create solutions that streamline your engineering efforts. Our ecosystem offers tools, hardware and software components, solution stacks, and complete building blocks for your INtime® based application.

## Middleware and Protocol Stacks

**acontis technologies**

Leading provider of EtherCAT Master Stack for INtime®, offering comprehensive EtherCAT solutions, tools, and services for control systems and system integration.

**.kenig**

EtherCAT specialists, providing advanced automation software and solutions, with a focus on serving system integrators and OEMs.

**straton by COPA-DATA**

Providers of the straton software, an IEC61131-3 automation platform tailored for OEMs, hardware, and software makers.

**TSEP**

Key member of the LXI* Consortium, with advanced test and measurement solutions that are integral to the LXI reference design.

## Software Building Blocks

**AXEL**

Dedicated to advanced software for industrial automation, offers the LogicLab* development environment to accelerate PLC development compliant with IEC 61131-3.

**ISAC**

At the forefront of PLC and motion control solutions, offering the Costantino CNC software built on the INtime® platform for real-time control.

**ISG**

Experts in machine tool and plant engineering software, with the ISG-kernel supporting EtherCAT, CANopen, Profibus, and other fieldbus systems.

**nexCOBOT**

A Nexcom* subsidiary offering a range of industrial computing solutions, including robot controllers and EtherCAT motion controls integrated with TenAsys® INtime® RTOS.

**REAL-TIME SYSTEMS**

Embedded virtualization leader, specializing in workload consolidation for deterministic and non-deterministic OSs on a single platform.

**RSI ROBOTIC SYSTEMS INTEGRATION**

Specialists in motion control technology, offering the RMP (RSI Motion Platform) for PC-based EtherCAT motion control with unique software tools and integration services.

## I/O and Hardware

**esd (www.esd.eu)**

Experienced provider of hardware and software products based on CAN and EtherCAT, focusing on customized automation solutions.

**hilscher**

Industry leaders in Ethernet and fieldbus communication, offering netX communication controllers and cifX PC cards for seamless automation system networking.

**HMS**

Specialists in industrial communication with CAN and LIN solutions under its brands, including Anybus*, Ewon*, Intesis*, and Ixxat*.

## Development Tools

**intel**

Intel's* software-first strategy means we design with developers in mind, removing the burden of programming different ways for different devices.

**Microsoft**

Driving digital transformation by merging the intelligent edge with the intelligent cloud, offering a suite of tools and platforms under the Azure* IoT brand.

## Platform Providers

**AAEON**

Leading AIoT innovator offering advanced motherboards, systems, and tailored solutions for industrial automation and OEM/ODM integration.

**ADVANTECH**

Global frontrunner in IoT intelligent systems and embedded platforms, specializing in industrial automation solutions from single-board computers to cloud computing.

**ASRock Industrial**

Global supplier of industrial systems and motherboards, focusing on developing reliable edge AIoT solutions for diverse applications.

**CONCURRENT TECHNOLOGIES**

Pioneers in critical embedded computing since 1985, offering high-performance single-board computers and other system-level products for real-time applications.

**kontron**

A leading IoT technology company delivering technologies for automated industrial operations, smarter and safer transport to advanced communications, medical, and energy solutions.

**Portwell**

Leading manufacturer of industrial embedded systems, offering both standard and custom solutions for various applications, with a focus on real-time and deterministic applications

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