White Paper

Industrial PC
Virtualization

Intel Transforms End-of-Life Industrial PC Challenges into a Long-term Advantage

Intel adopts a zero-disruption virtualization model to migrate legacy Automated Material Handling Systems and build a modern and resilient manufacturing framework.

Authored by Intel's Manufacturing Engineering Team, this paper details how Intel modernized its own fabs by virtualizing legacy industrial systems, cutting costs, minimizing downtime, and accelerating the path to Industry 4.0.

Intel Builds a Framework for the Future

Business success frequently hinges on having the right manufacturing technology in place. But for organizations attempting to put the concept into motion, various practical, technical, and functional realities can create roadblocks.

Nowhere is this more apparent than in the industrial computing space. Legacy industrial computers near or at the end of their functional lifespan make manufacturing operations and long-term equipment sustainability difficult. In semiconductor manufacturing, where equipment upgrades are capital intensive and require a longer return horizon, upgrades can further complicate matters.

As a result, it's critical to consider a more expansive framework for managing end-of-life challenges related to legacy computer systems. This paper examines a virtualization-based approach that combines modern hardware and legacy software to produce a more seamless equipment control framework that preserves legacy systems' business logic and workflows while migrating everything to a more sustainable and modern IT architecture.

Intel Manufactures a Better Hardware Approach

Modernizing a manufacturing environment is a daunting task. At Intel, an Automated Material Handling System (AMHS) manages and controls the movement of silicon wafers across hundreds of process steps in the fab. Industrial PCs act as the brain for various AMHS systems and components.

However, as with any control system in place over a long time, problems updating and upgrading industrial PC hardware and software began to appear. These challenges were especially apparent when Intel looked to replace components used in supply chain and inventory systems. Intel determined that a refresh and upgrade of the AMHS system was needed not only to maintain operations but also to bring the system into the era of Industry 4.0.

A virtualized technology platform built on the newest generation of Intel® technology-based industrial PCs accomplished both goals—and optimized dollars. By adopting a virtualized framework, Intel unleashed significant gains. These benefits included improved agility and flexibility, superior reliability, better data recovery, and a higher level of sustainability.

Legacy Systems = Risky Business

The starting point for the initiative was a recognition that the emergence of Industry 4.0 changed the stakes in profound ways. The performance and reliability of industrial PCs are critical in the operation of AMHS. Unfortunately, many manufacturers continue to rely on legacy industrial PCs. In some cases, these systems are more than ten years old, and they run on obsolete operating systems and software.

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Not surprisingly, these legacy environments introduce performance problems and boost operating and maintenance costs. Yet, while an industrial PC refresh makes sense on paper, the content migration process can prove daunting. A poorly executed migration can take the manufacturing operation down in a worst-case scenario.

Intel identified the AMHS systems that reached end-of-service and put together an end-of-life program. Some industrial PC's on these systems were several years old and replacement parts were scarce or non-non-existent. Based on a thorough risk-benefit analysis, Intel formulated the modernization strategy with minimum operational disruption.

The decision to move forward with modernization was based on three primary factors:

Risk of Failure: Hardware failures become more common on custom-designed legacy control systems. If a single component fails, it impacts the entire manufacturing system, which could lead to critical and expensive production disruptions.

Costly Maintenance and Support: There was a need for a more self-sustaining platform. However, the current industrial operating system (OS) was no longer available for purchase and was difficult to maintain due to its age. Making matters worse, the OS, and accompanying software relied on legacy Intel® Pentium® processors and couldn't run on more advanced hardware. Vendor support wasn't available for upgrading the existing hardware and OS.

Barriers to Innovation: The use of modern CPUs and network cards was limited due to the legacy OS. The older OS offered limited graphics driver support and made devices slower and more complicated to provision. Another major issue was that the OS didn't support modern multicore CPUs, making it impossible to embark on any form of hardware modernization.

Intel recognized that rewriting and updating systems would be extremely time and cost-intensive, with limited benefits. In addition, data sharing and support for existing network devices was impossible through an update. Finally, the existing legacy environment didn't support modern security.

The operational environment at Intel runs 24/7, so it was vital to ensure that there would be no disruption of the manufacturing process during the modernization effort. Over a period of nine months, a team analyzed the situation and identified three possible approaches:

- Upgrade all the components and systems within the existing framework.
- Develop entirely new software and systems.
- Build the existing platform into a virtual environment that could maintain the existing framework while supporting migration to modern supported hardware.

The first and second options would come at a cost of several million dollars or more, yet not address maintaining operations during the migration. On the other hand, the third option—virtualization— was a feasible way to modernize infrastructure at a much lower price. In fact, the cost ratio of virtualization was 17-20 times lower than the cost ratio of either of the first two options.

There were other significant benefits as well. Virtualization would allow Intel to operate the current system in a newer and far more stable environment, which would promote business continuity while supporting the development of new features. Finally, virtualizing the automation environment would allow Intel to improve operational reliability and system availability.

Mapping Out Key Requirements for Legacy System Migration

Intel's migration to the new AMHS framework began in the first quarter of 2021. It started with a systematic mapping process. Each legacy system consisted of the following components:

Not surprisingly, each of these components presented myriad challenges that IT and Intel's implementation team had to address at the infrastructure level. Challenges included determining the data migration path, the virtualization strategy, and support for graphics and

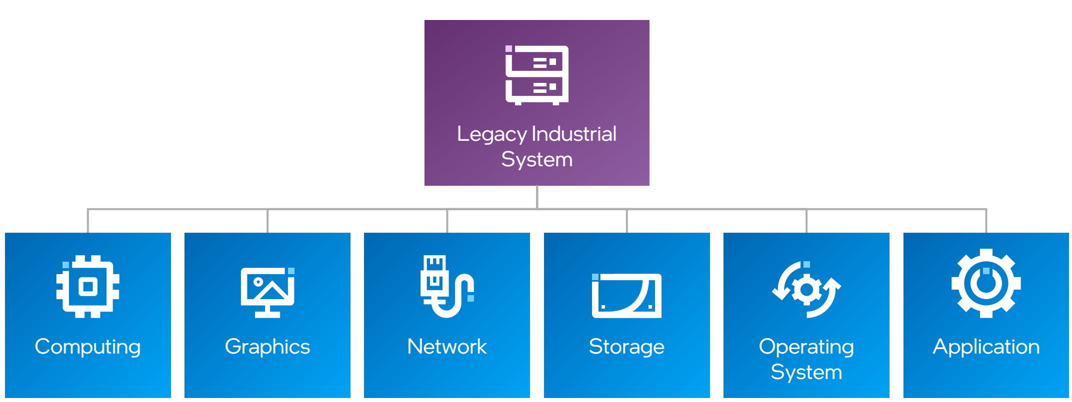


Figure 1. Legacy System Components

networking. These issues had to be fully addressed before any applications could be moved to the virtualized environment and the organization began using the new system. Intel focused on addressing key requirements within six broad areas:

Computing Requirements

- The legacy system had to operate within a single core virtualized environment.
- The virtualized hardware driver had to be compatible with legacy system drivers. New drivers were not available.
- Similar replacement hardware could no longer be procured as it was obsolete in the market.

Graphics Requirements

- All graphic hardware and drivers had to work correctly in the new virtualized environment.
- There was a need to launch a new application graphical user interface (GUI). For example, it wasn't possible to emulate the GUI used in the legacy system because the virtualization hypervisor wouldn't support the Video Graphics Array (VGA) BIOS configuration.

Network Requirements

- Driver support was a critical factor. The legacy system was equipped with only a handful of network drivers that were designed for use with network interface cards available at the time of its launch, several years ago.
- The virtualized environment had to be compatible with different network interface devices running inside a virtualized environment.
- The virtualized system had to meet the requirements of multiple network interface cards.

Storage Requirements

- Partitioning, including supporting legacy partition types, was vital.
- The system had to support specific partition types and boot records.
- The storage size of migrated systems had to be factored into the solution and needed to be flexible.
- Storage media had to interface for IDE/SATA/SSD.

Operating System Requirements

- It was necessary to preserve the legacy boot process.
- The system initialization sequence had to support modern hardware
- The OS had to support seamless inter-process communication with other control systems.

Application Requirements

- Control systems had to function on newer hardware.
- There was a need to preserve a digital gold copy of the legacy system.
- The OS and software had to work with the latest hardware.
- It was vital to manage data extraction from two architecturally different systems.

There were also broader requirements related to integrating all these components and systems, including selecting a virtualization platform and restoring the extracted digital twin. These tasks revolved around three critical challenges:

- Ensuring that the hardware was compatible when transferred from the old to the new platform, including the BIOS firmware and interactions with other I/O devices
- A need to build everything on top of a selected hypervisor framework
- Ensuring that the legacy OS and application would boot up successfully in the virtualized environment

Intel turned to a Linux-based Kernal-based Virtual Machine (KVM) open-source hypervisor to increase flexibility and help improve source code visibility. It mapped out the necessary changes to deliver the agility and flexibility required to test and deploy multiple versions of software while linking back to the original graphics BIOS using customizations.

> "Digital transformation is more important than ever. Often legacy compatibility complicates Industry 4.0 adoption. By leveraging proven IT technologies like virtualization, manageability, and communications, manufacturing operations can realize the benefits of Industry 4.0 more quickly. As someone who sits on the business's solution side, this framework is a great example of us practicing what we preach in our manufacturing facilities."
>
> — Adam Berniger
> Director, Industrial Solutions Division, Intel

A New Model for Legacy System Migration Takes Shape

Once the mapping was completed, Intel adopted a four-step process to oversee the actual migration:

Figure 2. Industrial System Migration Process

1 Extraction

Intel had to replicate the existing legacy system in the new environment, including system initialization, boot, storage, and application layers. The operating system running on the legacy physical hard disk of the industrial PC had to be extracted and saved into the newer storage device. This included an exact copy of the legacy image, which needed to be stored for future backup and recovery processes.

2 Restoration

Before approaching the restoration, the team had to decide which host environment and virtualization software it would use. Different virtualization software has different features and advantages that impact the legacy OS migration compatibility.

The image restoration took place throughout the virtual machine creation process. The restoration type depends on the extraction method used. The restoration process could be applied directly to the newer physical hard disk. Sometimes, it could require a newly created virtual disk as part of the restoration process—depending on the specific legacy content migration.

3 Deployment

The deployment involved the selection of modern hardware to meet legacy system functionality, reliability, and availability requirements. It meant that new hardware had to be easy to maintain and include readily available technical support. At the same time, it needed to meet all the previously listed virtualization requirements. At that point, it was necessary to configure a compatible virtualized environment and, finally, configure the legacy system application.

Figure 3 describes the legacy solution as compared to the new virtualized solution.

The solution for each of the legacy component requirements was as follows:

Computing Solution

Intel recognized that using KVM as an open-source hypervisor would increase flexibility and improve source code visibility. The use of KVM streamlined the implementation of required changes, including virtualization of the single-core environment and enabling compatible drivers in the virtual environment.

Graphics Solution

Intel turned to VGA BIOS emulation to address graphics requirements. This meant replacing the default SeaBIOS VGA BIOS cirrus type of binary file with the latest version or version 0.8a of LGPL VGA BIOS cirrus binary file—all while maintaining the same file linking and path to the existing QEMU image package that is specifically suited for a Linux-based hypervisor.

Network Solution

Intel recognized that it had to replace the end-of-life legacy ISA network cards with a newer network card. The physical network interfaces could be attached directly to the virtual network interfaces through virtualization technology. This also meant replacing default network drivers previously connected to legacy ethernet cards with modern network drivers that support a specific model of the virtual network interface.

Storage Solution

Moving to the new environment required several important changes related to storage. These included: converting disks to raw image files, virtualizing the IDE interface for legacy storage, virtualization using raw image copy, converting to raw image files to QCOW2 image files that could be compressed on the host system storage.

Operating System Solution

There was also a need to address operating system issues, including system initialization processes, virtual hardware driver initialization, and support for seamless inter-process communication with other control systems.

Application Solution

The final piece to the deployment puzzle involved establishing remote communication with subsystems, successfully launching the application graphic user interface, and handling application database and server initialization. This required legacy system-level configuration changes.

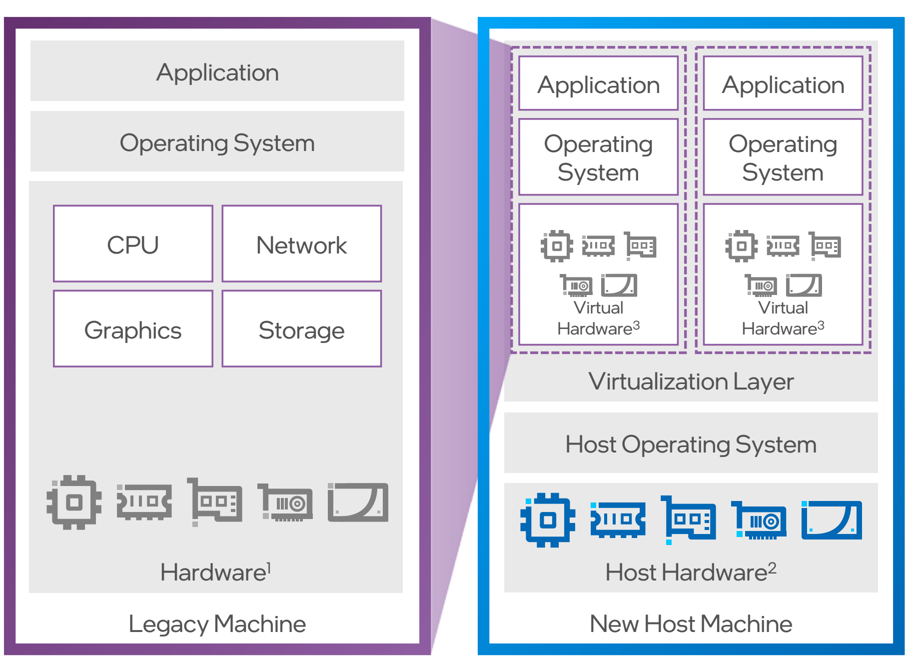


Figure 3. The legacy solution compared to the new virtualization solution. When Intel migrated to the new environment, a virtualization layer was added on top of the OS. The added layer allowed Intel to virtualize legacy content in the host machine.

[1] Some legacy devices can be connected to a new host machine and assigned directly to the virtual machine.

[2] Host hardware also can be allocated directly to the virtual machine if required.

[3] Virtual machine will default to virtual hardware if no host hardware is assigned.

4 Validation

The validation step ensured that all I/O devices and the legacy application were working correctly once the migration to the virtualized environment had been completed. Naturally, there were risks that existing devices drivers and applications used in the legacy OS would not function properly after the migration. The validation framework included system functionality, network communication, and hardware reliability.

A Framework for Efficiency and Innovation Emerges

In the end, Intel embarked on a series of changes and upgrades that resulted in a robust, reliable, and sustainable control system. Adopting Linux KVM to manage non-standard legacy industrial PCs delivered support in five crucial areas:

1. The AMHS legacy operating system booted successfully within the virtualized environment.
2. Legacy graphics rendering and GUI porting are supported.
3. Network and database communication with subsystems are supported.
4. The remote management of host and subsystems was enabled.
5. AMHS legacy software was successfully running inside the virtual machine.

As a result, a more advanced level of functionality took shape, resulting in several key benefits, including:

- **The legacy software is preserved** while realizing gains from a virtualized environment with more modern hardware.
- **More manageable and sustainable hardware** exists at the host system level. Intel helped improve system reliability through upgraded hardware estimated to be three times as efficient compared to the legacy system.
- **Cost avoidance related to equipment upgrades** and the development of new applications. A gold copy now preserves the original system for future applications and integrity validations.
- **More improved data recovery capabilities**, including compression and consolidation in a centralized server.
- **Hardware selection flexibility** through an emulation mechanism, making modern hardware a feasible upgrade path. It established a framework for migrating a variety of legacy industrial control operating systems used in semiconductor manufacturing equipment.

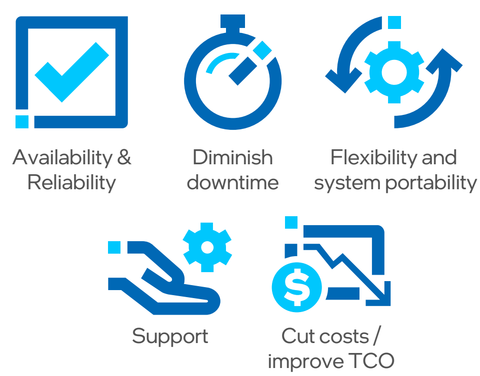
This virtualization technology foundation promotes a more sophisticated framework for business continuity and managing legacy systems. It makes it possible for Intel to transition to modern hardware without disrupting semiconductor manufacturing.

> "When it comes to sustaining legacy mission-critical systems, one needs a solution that is secure, reliable, and scalable. Virtualization technology paves the way forward through bridging modern hardware and software."
>
> **— Anita Ingro**
>
> Director, Foundry Automation, Intel

Intel Embraces the Future

This virtualization project demonstrates how organizations can shift from legacy to modern hardware without experiencing major disruption. The virtualization approach made it possible to:

- **Boost availability** and reliability.
- **Diminish downtime** through improved recovery.
- **Gain flexibility** and system portability by isolating the application and operating system layers.
- **Support legacy** components that are no longer procurable and sustainable (through hardware abstractions).
- **Extend the life** span of equipment and software, thus cutting costs and improving total cost of ownership (TCO).



Thanks to virtualization technology, Intel is now positioned for more efficient and cost-effective semiconductor fabrication while continuing to use its advanced legacy control systems. While some aspects of the project continue to unfold—including upgrading industrial PCs and OS software over time—today's virtualized environment allows tasks to be completed in a far more seamless and straightforward manner. Over the short term, Intel has gained improved business continuity. Over the long term, Intel is equipped to add new AMHS tools and technologies as they appear. It's a recipe for success.

Unleash the Future Potential for Industrial Excellence via Intel® Virtualization Technology

Migration from a legacy PC platform to a modern industrial PC platform doesn't only address hardware end-of-life issues related to business and operational continuity; it lays a foundation for technology advancement and Industrial 4.0 transformation.

Intel identified four critical factors that simplify hardware setup, reduce operational costs, and increase manufacturing productivity. These factors will help revolutionize and transform the manufacturing landscape and ensure that the system stays current with evolving business and productivity demands. The factors included:

Workloads can be consolidated on fewer industrial PC platforms
At Intel, the migration from a legacy platform to a new industrial PC platform increased overall computing power significantly. Legacy workloads can now take full advantage of the upgraded computing resources. In fact, it's now possible to increase the utilization of computing resources by consolidating multiple AMHS OS instances into fewer industrial PCs. In addition, Intel was able to trim hardware inventory and lower maintenance costs while simplifying physical infrastructure setup.

The virtual machine (VM) can unleash additional workload capacity alongside the legacy OS
The hardware capabilities of the new industrial PCs can integrate and support modern intelligent workloads while continuing to run legacy systems' OS. This allowed for things like predictive AMHS maintenance and smart factory technologies that use sensor data and vibration-based monitoring.

The VM framework supports zero interruption for future maintenance and upgrades
Virtual technology supports zero interruption of manufacturing operations during hardware upgrades and maintenance. What's more, it's possible to complete a live virtual machine (VM) migration to another system, which greatly simplifies upgrades and maintenance. In addition, downtime is minimized, and productivity increases through non-interrupted operational continuity.

Improved device manageability
With a modern industrial PC platform that includes Intel® Core™ vPro® processors, IT can respond amazingly fast to reduce work interruptions. As part of the Intel vPro platform, Intel Active Management Technology (AMT) includes remote management features that allow IT to remotely discover, monitor, repair, restore, and help protect systems even when devices are out of band, on-premise, or off-premise

The benefits don't stop there. Administrators can perform remote system actions such as reboot, power up, power down, system updates, and BIOS configuration changes. It's even possible to manage systems that are in powered down state. Minimizing IT staff access to physical systems can be critical. At Intel, it's now possible to better protect the highly sensitive cleanroom space.

Learn more about Intel technologies for Industrial 4.0

- Intel Industrial PCs
- Intel vPro® Platform

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