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IT@Intel: Optimizing Factory Performance with Digital Twin Technology

How Intel® Automated Factory Solutions delivers tremendous benefits to semiconductor manufacturing environments.

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Overview

The idea of creating replicas of real-world objects is not new. Architects, for instance, have long built models of the buildings they propose to create, giving themselves and clients new perspectives that are much more tangible and informative than sketches, or even detailed blueprints.

But architectural models are static. Today, the ever-increasing technological capabilities of computers equipped with high performance processors mean we can digitize the concept of modeling, raising it to new, dynamic levels. Now, instead of simple physical replicas, we can build Digital Twins (DTs)—data sets that simulate not only the physical attributes of entities (such as shape, color, and size) but also more abstract characteristics (such as strength, elasticity, conductivity, and many more). Plus, once created, Digital Twins of different objectives can be combined into Digital Twin systems, their behavior mimicking that of their real-world counterparts. That behavior can be recorded, analyzed, tested, and revised cyclically.

With Digital Twins, we can now:

- Design new systems, such as complex factory operations, and study their behavior and capabilities with much more flexibility.
- Experiment with Digital Twins of existing systems to understand the ramifications and risks of changes prior to implementing in the real world.
- Learn how to carry out physical tasks using Digital Twins instead of actual objects, simplifying and accelerating training courses.
- And much more, as we'll see later.

Digital Twins are changing how we design, build, and manage a wide variety of objects and systems, from simple consumer products to vast, complex manufacturing facilities.

For all these reasons, the Digital Twin market is growing rapidly. Analysts predict a compound annual growth rate of between 31.9% and an explosive 51% by 2030[1, 2]. This paper will look more specifically at how Intel is leveraging Digital Twins in their plants and how they're making that expertise available to manufacturers around the world.

Digital Twins in Manufacturing

The US National Aeronautics and Space Administration (NASA) was one of the first organizations to make use of digital twins. By replicating systems built to be used in space, Apollo 13 engineers famously solved problems encountered in space by creating digital models to simulate them on the ground.

Since that time, the use of Digital Twins has expanded into a wide variety of other industries, with manufacturing being one of the most fruitful of these. The ability to represent objects and functions digitally has opened an enormous range of new possibilities for manufacturing engineers and technicians, who can now simulate a wide variety of operations quickly and without risk of damage or disruption of operations.

In 2002, Dr. Michael Grieves, now Executive Director and Chief Scientist at the Digital Twin Institute, introduced the concept of the Digital Twin into product lifecycle management. DTs have proved invaluable in a wide range of manufacturing environments, including discreet manufacturing (individual items such as cars, planes, semiconductor wafers, and processors), process manufacturing (chemicals, petroleum, pharmaceuticals, etc.), and more. In fact, the use of DTs is one of key elements of the revolution in manufacturing known as Industry 4.0. At its most basic level, Industry 4.0 deals with the application of digital data and processes to manufacturing. Ground-breaking technologies such as robotics, autonomous machines, additive manufacturing, and machine learning and artificial intelligence enable companies to improve product output and quality while reducing costs.

Digital Twins deliver significant business benefits to manufacturers:

- Manufacturing facilities require extraordinary funding to design, build, run, and update. DTs optimize the use of these expensive capital assets.
- The efficiency of specific manufacturing processes can drastically affect production and profitability. DTs enable the streamlining and tight management of these processes.
- Improved availability of important data is critical; faster data means better issue resolution and prevention.

More specifically, Digital Twins enable manufacturers to perform a number of operations far better than they could previously. For instance:

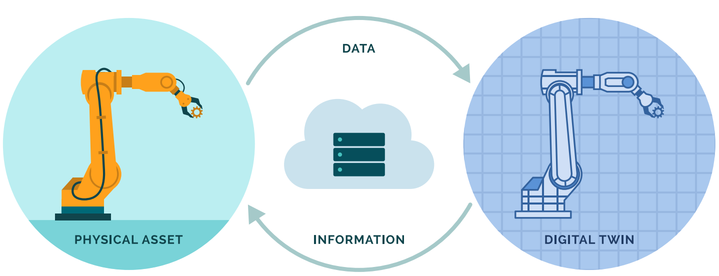


Figure 1. A Digital Twin can be updated as conditions change.

- Product designers can create highly accurate 3D digital models of components, from a single screw to an entire factory floor plan.
- Engineers can use the DTs they've created to build simulations to predict the outcomes of processes when there are variations in the process. To do that, they simulate actual plant operations using real-time data and introduce data representation of the what-if scenarios to produce the end results.
- Companies can plan new factory installations or modify existing ones to improve production and lower costs.
- Factories can centralize data into a single hub, with the DT connecting every production machine in the plant through data sensors. This means that the virtual model can receive and act on real-time feedback and store important data for analysis.
- DT users can view operations parameters via software dashboards or websites in real time, reacting immediately as necessary.
- Backoffice operations can be simplified. For example, DTs can drastically reduce manual data collection and paper-based procedures.

Typical Digital Twin Use Cases

Once a Digital Twin has been created, it can be used in virtually endless ways across a wide range of industries:

- DTs of buildings can be proactively monitored using IoT sensors to check for signs of wear or damage that need repair.
- A DT of an air-conditioning unit can be tested to see what thermal conditions will result in overheating.
- On-site repair crews can use DTs on mobile workstations to pinpoint precisely where components in a manufacturing facility are malfunctioning.
- Electrical designers can increase digital amperages in the DT of a set of server racks to check for potential overloads.
- Engineers can optimize a product's performance by creating prototypes and testing them at various points in the design process.
- DTs can improve the efficiency of supply chains by more accurately forecasting scheduling and logistic demands.

And many other industries are finding DTs equally valuable, including in fields as diverse as healthcare, environmental safety, utilities, and government.

Digital Twin Capabilities

In broad terms, Digital Twin software can be categorized into three different types:

Level 1: Descriptive Twins

Level 2: Informative Twins

Level 3: Predictive/Autonomous Twins.

Level 1: Descriptive Twin

The Descriptive Twin is an engineering design and visual representation that embodies knowledge of a physical object or set of objects. As humans often benefit from visually perceiving an object, Descriptive Twins can be implemented in a variety of use cases. One example, as mentioned above, is architectural models, which enable clients to see what the end product will look like. Descriptive twins can also be helpful for training; augmented reality environments allow students to practice simulated physical actions with materials and tools, without actually accessing those tools (or risking the consequences of misuse).

Figure 2. A Descriptive Twin can provide viewpoints prior to construction to enable fast design revisions, as with this retail layout.

One example of Descriptive Twin technology involves factory use of Augmented Reality (AR).

AR headsets supplement reality by overlaying digital content in the user's field of vision, helping the wearer perform a broader range of tasks than would otherwise be possible. For instance, in the past, Intel equipment technicians used paper checklists when performing preventative maintenance tasks; now they refer to digital checklists that are always available and easy to update and save. They can call up and view schematics of equipment they're working on, or watch live video streams showing each stage of a complicated repair or parts replacement. They can even view and manipulate 3D holographic images of machines and parts.

Used in training, AR enables students to practice skills in the classroom instead of on the factory floor. It can be used to simulate manufacturing situations and to experiment with different design scenarios, even those involving complex systems and processes. For example, teams can work in collaborative AR environments, with everyone viewing the same situation; this means that experts can work remotely with on-site technicians to provide real-time guidance.

Figure 3. AR speeds complex physical tasks.

For instance, Intel uses AR in manufacturing fabrication plants ("fabs") for several different tasks. It delivers crucial benefits, including:

- Higher production yields, thanks to reduced maintenance times.
- Less time needed to deal with tool errors.
- Faster time to training completion for technicians.
- Reduced machine time devoted to training, resulting in increased production uptime.
- Increased technician flexibility that enables technicians to handle a wide range of tasks.

Figure 4. AR puts production details at technicians' fingertips.

Level 2: Informative Twin

An Informative Twin is similar to a Descriptive Twin but includes an additional layer of operational and sensory data. This enriched data can enable users to extract insights about how the object will perform in the real world. One example is Intel's creation of informative Digital Twins of processor fabs, complete with equipment, material handling systems, and computer-integrated manufacturing systems. These capabilities enable even more expanded possibilities, such as a "lights-out" factory, where the entire operation is monitored and managed remotely—without direct human interaction. Today, for instance, a single process technician can manage hundreds of different machines and devices from a single remote operations terminal.

In fact, Remote Operations Centers (ROCs) made possible by Informative Twins are changing how manufacturing facilities are staffed and run. They enable technicians to control and manage the factory floor from anywhere, including from home. A single ROC station can monitor and control hundreds of production tools and can collect input from numerous edge PCs and incorporate it into a detailed picture of the current status of the factory floor.

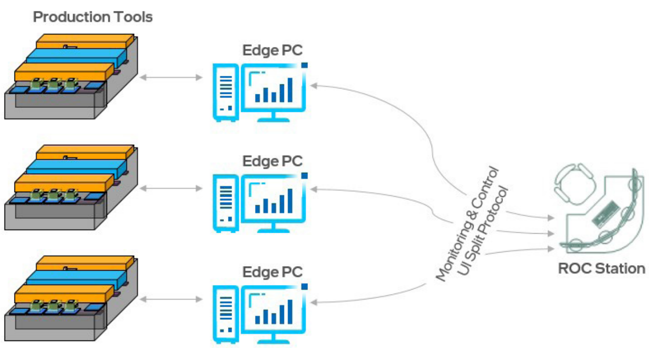


Figure 5. Many tools, one workstation.

Level 3: Predictive/Autonomous Twins

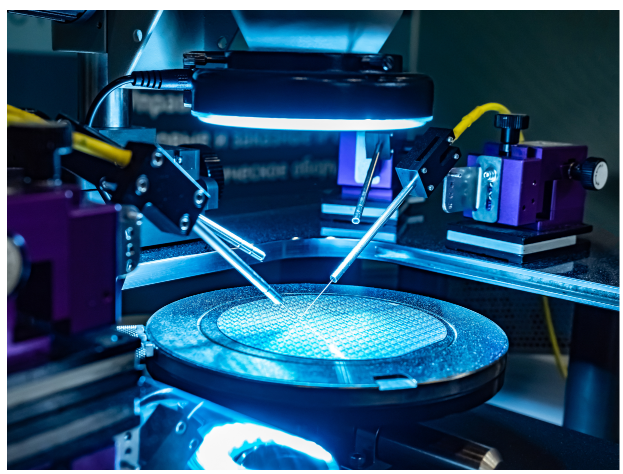
Predictive/Autonomous Twins incorporate updatable models that can be used to drive actionable tasks. This type of twin can learn, make decisions and act on behalf of users, with or without human interaction. The status of the Twin can be continuously monitored, and actions taken to correct problems or to coordinate continuous processes, such as the systematic feeding of materials to a machine tool. To keep things running smoothly, the software can execute what-if scenarios through a simulation engine, adjusting workflows as needed. This results in more efficient use of materials and helps prevent supply chain inefficiencies.

Predictive/Autonomous Twins also enable users to make accurate predictions of unmeasured quantities and future states, based on historical data. A good example is an Automated Material Handling System (AMHS) Digital Twin at an Intel fab.

The primary role of the AMHS is to load, transport, store, and unload silicon wafers efficiently and effectively from one machine to another. Using a digital twin not only enables remote monitoring and management of the system, but also enables engineers to predict various production metrics accurately and identify/solve problems quickly. And Predictive/Autonomous DTs are designed to learn from experience, helping them to more quickly identify patterns and provide early warnings of problems. As overhead vehicles (OHVs) are usually in motion, and their routes sometimes span the entire campus, it is difficult to characterize the behavior and performance of the entire AMHS without a birds-eye view Digital Twin.

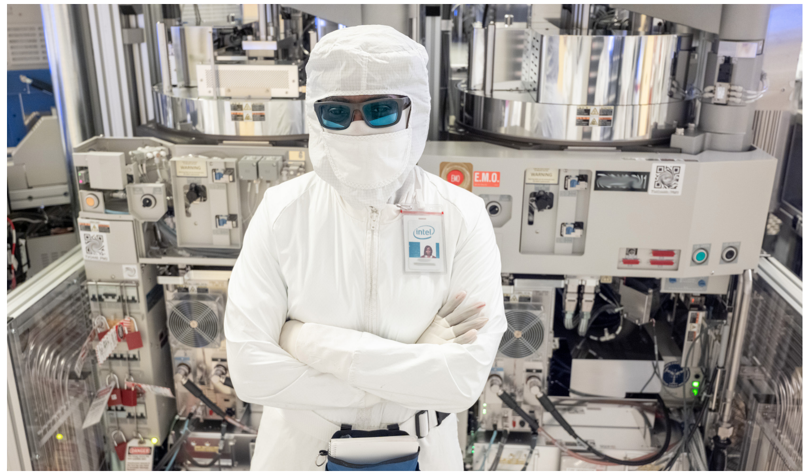
Predictive/Autonomous Digital Twins provide several key benefits for sophisticated manufacturing:

- **Monitoring.** An AHMS DT delivers comprehensive, bird's-eye view capabilities for monitoring and managing materials handling. It enables engineers and technicians to quickly identify potential problems and bottlenecks, take action to re-route traffic to decrease congestion, dispatch technicians to repair failures, and increase production efficiency.
- **"What-if" Planning.** Long manufacturing cycle times with repeated processing using the same equipment over and over for different operations can be problematic in terms of efficiency; careful planning and monitoring are required to ensure that equipment use is optimized. Without a proper manufacturing simulation system that enables "what-if" scenario planning, manufacturers run the risk of "ping pong" problems where products are repeatedly transported from machine to machine (or even fab to fab) in a non-optimized flow, wasting time and equipment capacity.



- **Reducing Downtime.** By modeling physical assets and operations, DTs enable factories to anticipate downtime in advance and react to fast-changing variables. Because data is constantly being recorded, operators can easily access, inspect, and evaluate performance across the entire plant life cycle.

Digital Twins and Semiconductors



All of the Digital Twin capabilities above are highly relevant to the semiconductor industry, where the digital transformation actually started over forty years ago, in the 1980s. In that era of chip manufacturing, workers in Intel processor fabrication plants tracked materials on paper, and a lot of tool-to-tool silicon handling was performed manually. Over the years, chip manufacturing steadily increased in complexity, and of course, demand for chips exploded exponentially, both of which drove the evolution of processor fabrication toward increased digitization.

Starting in the 90s, Intel massively digitized wafer production by implementing highly integrated factory systems, including tool controllers, manufacturing execution systems, advanced process control, and automated material handling systems. In the early 2000s, fabs saw further steps toward digitization by introducing remote operations centers that enabled a fab to be monitored and managed from off-site. With the introduction of Industry 4.0, Intel quickly adopted many of the strategies inherent in this revolutionary development to help meet the challenges of increasingly complex microprocessors and other components. These efforts have proved highly successful: harnessing the power of DTs has been a true game changer, streamlining processes and reducing costs. Intel has been able to significantly increase per-person productivity and reduce unit throughput time while maintaining outstanding product quality, even as microprocessor manufacturing procedures have exponentially increased in complexity.

Intel® Automated Factory Solutions (Intel® AFS)

With the promise of Digital Twins firmly established, Intel formed the Automated Factory Solutions team in 2019. Its mission is to leverage Intel's hard-earned expertise in manufacturing automation software like Digital Twin technology and provide it as commercial products for other manufacturers around the world.

Intel AFS Digital Twin software inspired by solutions implemented in Intel fabs have provided tremendous benefits to the industry leader in microprocessor production. Now these solutions are available for use by other discrete manufacturing companies.

Intel Automated Factory Solutions is a suite of products that embody the experience Intel has gained implementing DTs. Designed specifically for high-end technical manufacturers, these products are custom-fit to meet each customer's unique operational challenges. Expert Intel engineers work on-site with customer stakeholders each step of the way, from initial product planning up until all systems are online, running, and producing.

Intel Automated Factory Solutions	
Intel® Factory Pathfinder	High-speed discrete event simulator for factory optimization.
Intel® Factory Recon	Full graphical digital twin of factory production equipment and automated material handling system.
Intel® Factory Optimizer	An AI-based control layer for Factory Pathfinder.
Intel® Factory Adapter	Adapting the factory process to the environment in two specific ways: (1) Automated measurement step-skipping and job parameter processing engine with decisions based on quality or other relevant data. (2) Dynamic equipment process job customization necessary to meet specific process rules in the factory.
Intel® Factory Pathfinder for Enterprise	Moving Factory Pathfinder simulations into the enterprise layer to enable rapid product allocation and customer order response times.

Intel® Factory Pathfinder

Intel Factory Pathfinder delivers advanced simulation and scheduling capabilities for manufacturing.

Factory Pathfinder uses Digital Twin technology to provide manufacturers with critical capabilities designed to improve processes, increase efficiency, and reduce costs. As a simulation-based system, Factory Pathfinder can digitally model the entire factory floor, including machines and infrastructure, and can recreate the flow of materials through the system, as well as the many processes involved in turning raw materials into finished product. Factory Pathfinder can even help manage product handling in multi-factory environments, optimizing the movement of products within and across facilities to help reduce the cycle time of each individual product through the manufacturing process.

With Factory Pathfinder, companies can turn disorganized and wasteful processes into organized systems, reducing "ping pong" problems and increasing productivity, as shown in Figure 6.

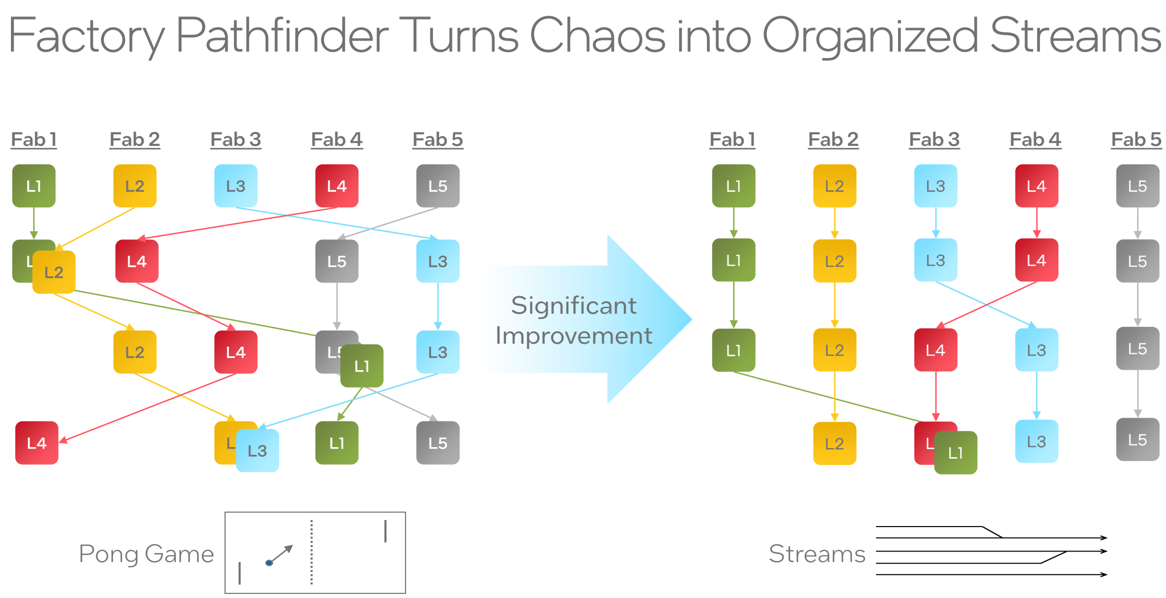


Figure 6. Streamlining materials handling.

As shown in Figure 7, Factory Pathfinder can significantly optimize product movement between separate manufacturing facilities, removing wasteful moves and keeping product output at equivalent levels.

- Problem: Multi-factory campus Automated Material Handling System (AMHS) building link capacity is stressed ahead of expansion.
- Solution: Intel Pathfinder greatly reduces product movement, saving tens of millions of dollars (and more).

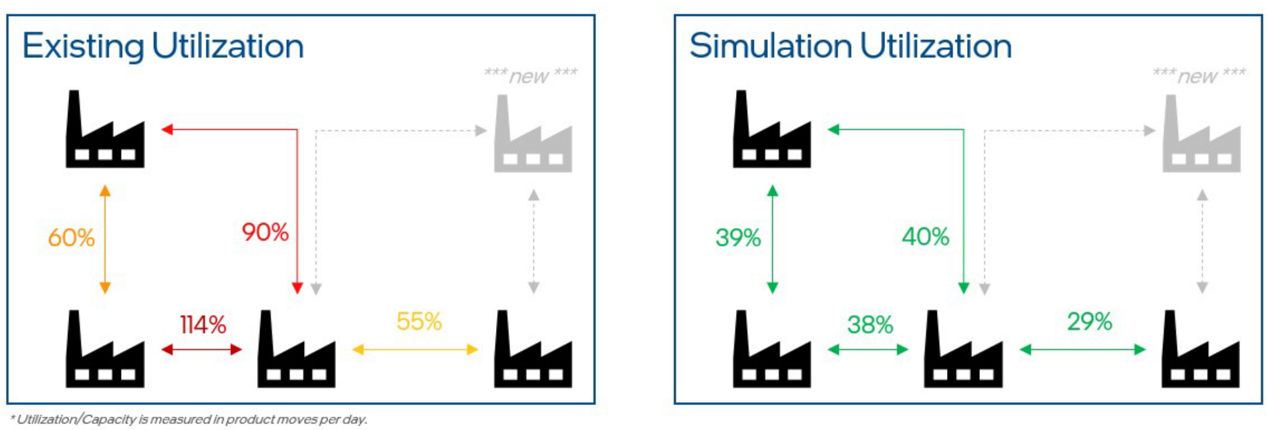


Figure 7. Greatly optimized product movement.

Intel® Factory Pathfinder for Enterprise

Also, in planning and development is Factory Pathfinder for Enterprise, which extends the factory management capabilities of Factory Pathfinder, as shown here. Manufacturers can use it to optimize factory output, streamline product assignment to factories, reduce order fulfillment times, and better balance conditions on the factory floor to match current product demand and material availability.

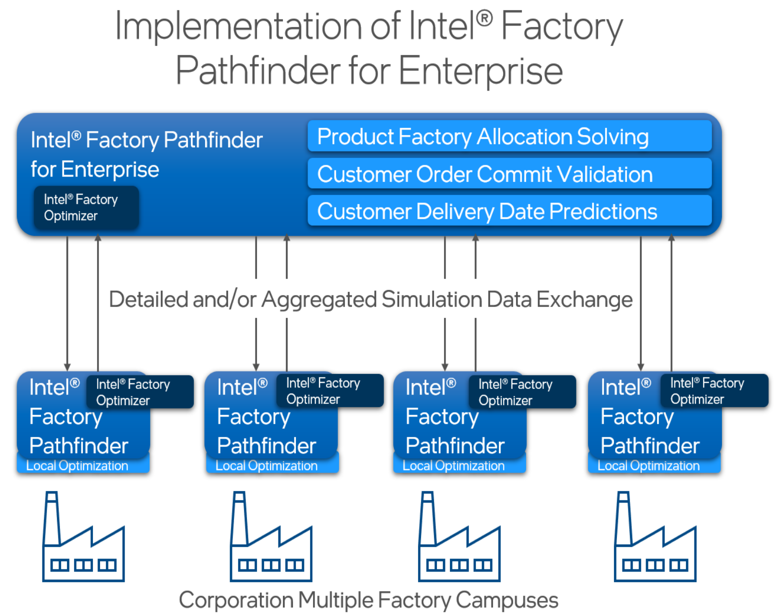


Figure 8. Intel® Factory Pathfinder for enterprise.

Intel® Factory Recon

Factory Recon enables manufacturers to use game-like, immersive graphics capabilities to instantly visualize their operations better than ever before—how they're running now, how they ran in the past, and how they might run in the future. Thanks to this enhanced visibility into their operations, companies can dramatically reduce Mean Time to Repair (MTTR) for factory incidents. Factory Recon not only serves as a factory incident detective system to investigate problems, but also as a flexible simulation application for modeling "what-if" scenarios.

Figure 9. Intel® Factory Recon Graphical User Interface (GUI).

Factory Recon works in several modes:

Live Mode
Presents AMHS information in a single panel view, so managers can quickly view the entire factory operation, including AMHS, production equipment status, error warnings, and more. Problems can be discovered more quickly, mitigating cascading impacts to other areas in the plant. Plus, managers have quick access to detailed status reports.

Playback Mode
Think of this as a rewind button for manufacturing activity: managers can quickly load data and run playback for specific windows of time. They can visually inspect process steps, run detailed analyses, and automatically collect data and metrics. In many instances, this can be a game-changing tool, reducing problem resolution times from days or weeks to minutes or seconds.

Simulation Mode
"What-if" scenarios are valuable tools for planning the physical movements of materials and equipment. Using this mode, engineers can dial in specific conditions to understand their effects on production throughput, then analyze the results in detail before finalizing often-expensive modifications to equipment or procedures. For example, will reconfiguring equipment in a specific location in the factory result in a traffic jam within the AMHS? Use Factory Recon simulation mode to find out.

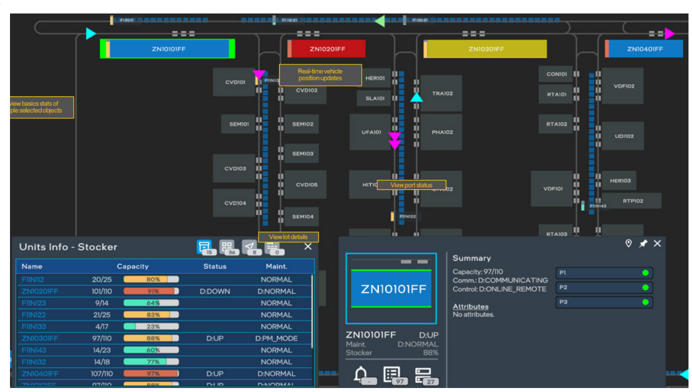


Figure 10. Intel® Factory Recon display of factory floor.

Intel® Factory Optimizer

Factory Optimizer is an AI-based control layer for simulation optimization and offline analysis. It's a powerful tool that allows engineers to quickly and easily test changes to factory assets or conditions. For example, they can compare two different devices to see how they perform in the real world, or modify machine layouts to minimize materials transfer time. In addition, Factory Optimizer is capable of sophisticated analysis; for instance, it can be used to run thousands of simulations in parallel to generate datasets for AI and ML algorithms. This greatly saves time and effort for engineers working to optimize factory flow.

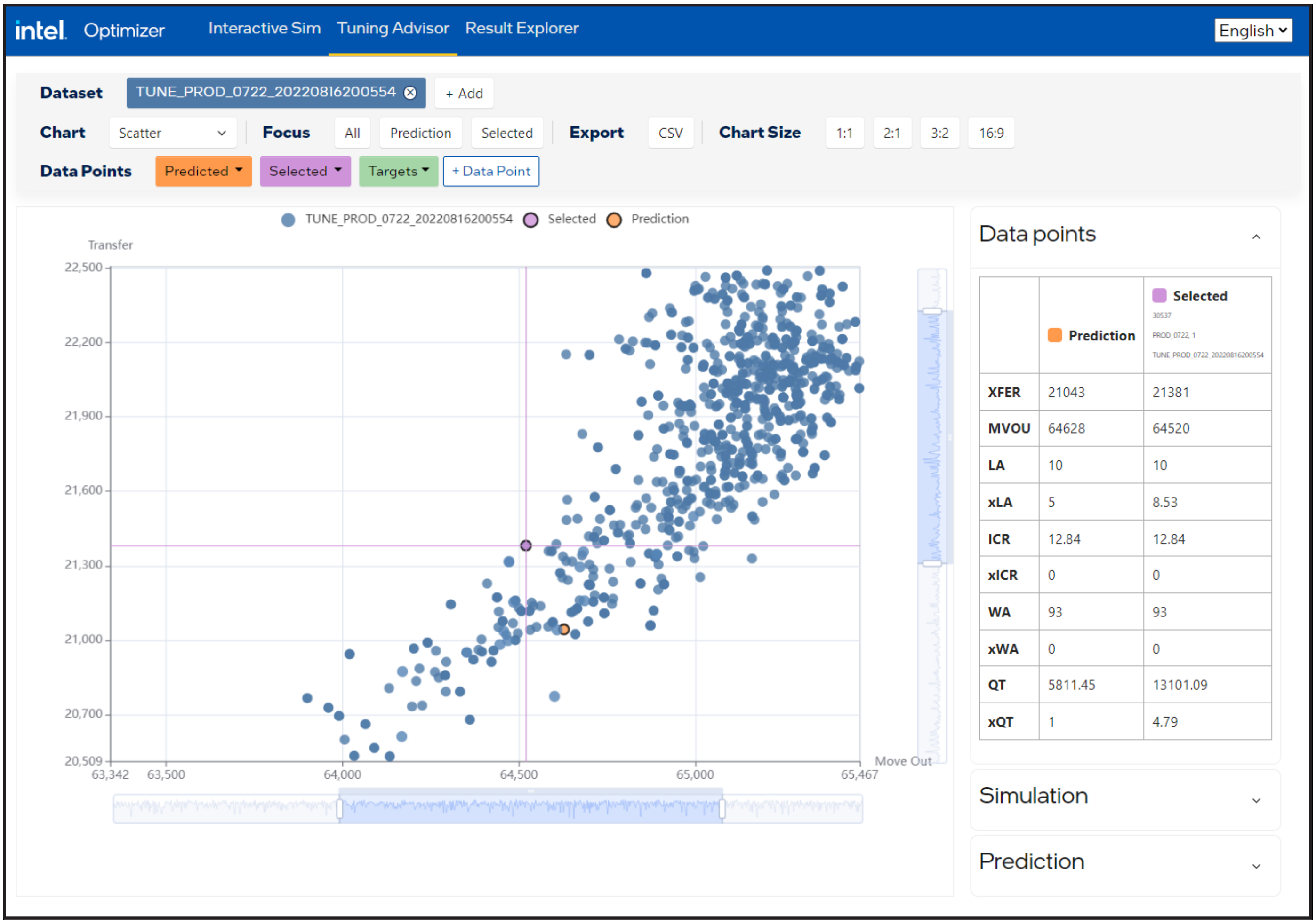


Figure 11. Intel® Factory Opimizer – Comparing the result between generated datasets and prediction result. The AI-based prediction will update the result when engineers make changes to factory conditions.

Intel® Factory Adapter

Factory Adapter is an automated measurement step-skipping engine that makes decisions and builds intelligent sample plans based on factory quality data. It helps increase product throughput by reducing redundant or unneeded steps in the manufacturing process, thereby optimizing the use of capital assets. It can also help make decisions on processing job parameters to adjust the manufacturing process as needed in real time.

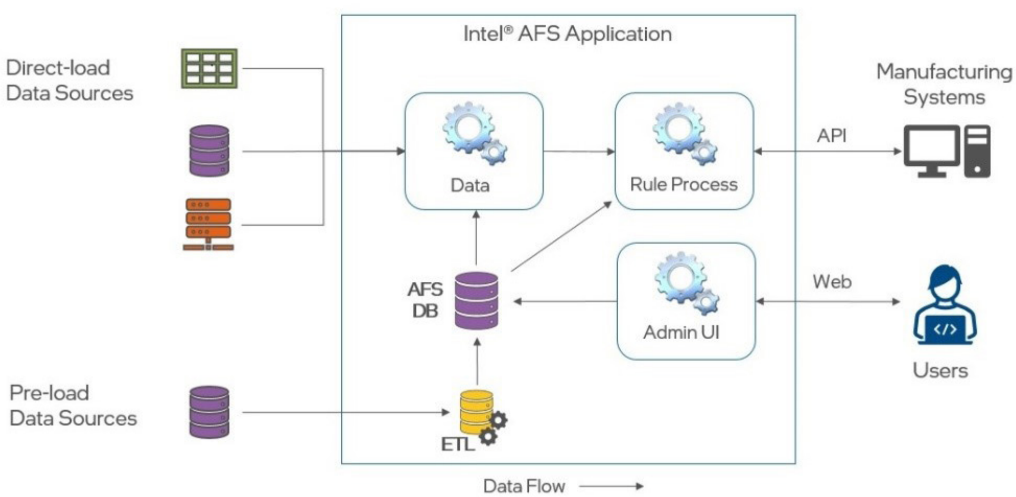


Figure 12. Intel® Factory Adapter basic architecture.

How Intel Processors Power Digital Twins

As we've seen, Digital Twins are powerful, specialized software tools. As such, they demand high-performance hardware. Intel provides the processors manufacturers need to power the groundbreaking factories of today and tomorrow.

Intel® Xeon Scalable Processors

Intel® Xeon® Scalable processors offer a balanced architecture with built-in acceleration and advanced security capabilities, designed over decades of innovation for the most in-demand workload requirements—all with the consistent, open, and proven Intel architecture. In addition, Intel Xeon Scalable Processors come with built-in accelerators to deliver the levels of server performance needed for demanding manufacturing environments.

Intel® Core™ Processors

These processors power high-end PCs with industry-leading CPU performance for discrete-level graphics and AI acceleration and outstanding performance for a variety of applications, including manufacturing programs such as control room dashboards, website management, Digital Twin manipulation, and more.

Conclusion

It's no exaggeration to say that Digital Twins technology is changing the way manufacturing engineers conceptualize their world. The ability to build and interact with digital representations of machines and systems enables a deeper understanding of complex factory operations, resulting in game-changing improvements in efficiency, effectiveness, and product quality.

Intel Corporation embraced Digital Twins to transform their microprocessor fabs. Now Intel engineers have packaged this technology and made it available to manufacturers around the world. As Intel's successful adoption has proved, Digital Twin technology can deliver tremendous benefits and cost savings for manufacturers today, and tomorrow.

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1. Intel White Paper: Driving Data Transformation of Smart Factory with Digital Twin Technology.
2. Research and Markets, www.researchandmarkets.com/reports/5128896/digital-twin-market-research-report-by-type.

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