Value creation with plant modelling and simulation

AFRY and Siemens showcase Real Digital Twins

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Content

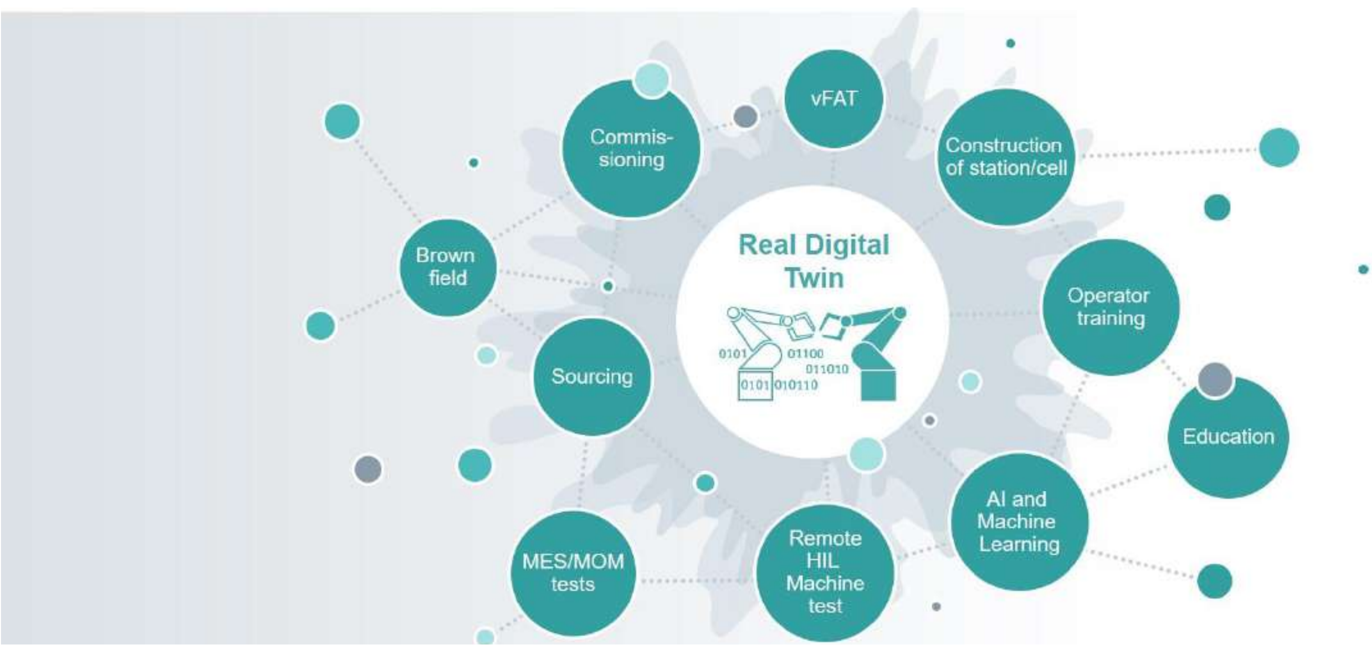

Figure 1- Real Digital Twin as central element to improve Operations

Executive Summary

Digital Twins seem initially like a stage to achieve towards the end of a digitalization journey. However, this paper shall provide the reasoning and motivation to place the digital twin at the beginning of the digital transformation of automation processes. The benefits are accelerated collaboration and frontloaded iteration to increase quality and reliability. Enabling key concepts of Industry 4.0, a digital twin allows for more efficient operations during planning, development, runtime, and changeover. [1] [2]

Most industrial companies must face big challenges like shorter time-to-market, cost reduction, better quality, and increased flexibility to adapt to market changes. Digitalization seems to hold the answer to these challenges. Through new, disruptive technologies like digital twins, AI, edge computing, cloud services, traditional workflows can be shortened. So how can digitalization address these complex challenges? [3]

The wide variety of topics makes it hard for companies to find the right way. One of the topics that already has a good degree of maturity and can make a really big impact is the digital twin and is therefore the core component of this white paper.

Siemens' Digital Enterprise portfolio and AFRY's engineering services offering an easy entrance with fastest return of investment (ROI).

Talking about a digital twin means in this context talking about a digital copy of a component of a machine, a single machine, a production line or even a whole plant. Different usages of a digital twins can be seen in Figure 1. The digital twin is not limited to a single phase in the development process. It has impact and relevance for the entire life cycle, from the early design stages onward through commissioning, operations and retrofit. Therefore, an important aspect is the combination of models that are developed during the life cycle and used for various purposes. These digital twins will enable closed loops where data driven improvements can be made, as can be seen in Figure 2.

From the experience of AFRY and Siemens it can be concluded that a lot of companies have difficulties in introducing appropriate technologies like digital twins due to the complex and difficult evaluation of the ROI. Therefore, it is essential to reduce the risk of investment projects by demonstrating the value of digital twins. One demonstration of this can be seen in Figure 3, where it is clear that digital twins does not only enable shorter commissioning time, but also reduces risk during the ramp-up phase, saving producing companies many hours of production downtime. This white paper will further show how and what can be enabled with a digital twin and proves how to benefit from it in different field of applications.

Driving digitalization in production is not only about technology, but also how technology improves culture, collaboration, competence, and leadership in order to lower effort and increase productivity.

Independent from your maturity within the digitalization journey - it will be crucial to create digital twins of your machinery to enable the present and futures ways of working.

The return of investment of digitalization through digital twins has proven to be immediate – not related to long payoff periods – as certainty and efficiency increase through its application.

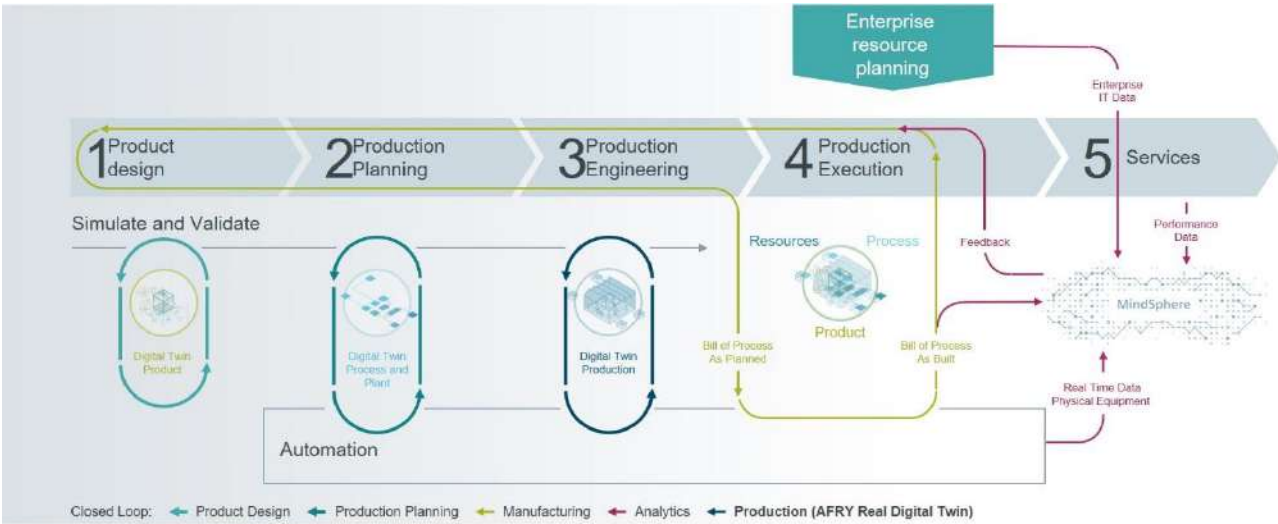

Figure 3- Different Digital Twins in Product and Service Life Cycle

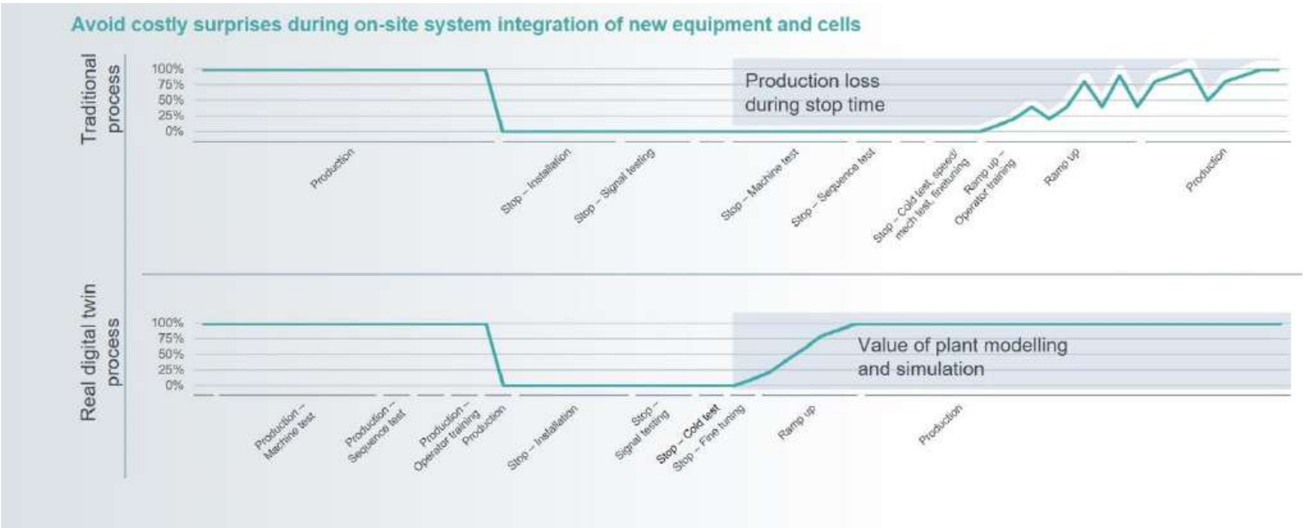

Figure 2 - Experienced benefits during production line rebuilding projects by applying plant virtualization including a Real Digital Twin

Challenges and Potential

Challenges within the industry

How to capture value of digitalization initiatives

Digitalization is described as the way to maximum efficiency, but clear connections are often missing, as it seems to come with a high entry burden.

Within the operations of a manufacturing company, the KPI for successfully implemented digitalization initiatives are challenging to identify.

The industry is looking for reference cases to adapt but is hesitant to lead the way. Therefore, use cases are often based within an academical motivated collaboration and deemed futuristic. [2]

In this paper we would like to propose KPIs for the digitalization of industrial operations, and a list of reference cases to argue visualize improved changeover and ramp up times.

Digital Anxiety

Digitalization offers a vast potential to create value and avoid waste but can seem overwhelming in its complexity and meaningful application.

Our human confirmation bias will point us back to the existing way of working, a routinized, proven setup, adapted to the organization, with output to prove it.

Avoiding the unknown, difficult to understand, potentially better, or potentially worse process at the other end of digitalization.

When faced with a decision for coming projects we overate existing practices as they seem to be proven and untouchable, unwilling to disrupt the operation with new technological advances.

Complex system architecture

Both product and production complexity as well as the complexity of available digital solutions seem to bare a great risk of making the wrong decision.

Industrial operations are often handling a complex system landscape. Multiple suppliers of systems, tailored interfaces between IT systems (e.g. ERP, MES) and OT systems (DCS/PLC, SCADA, Historian) missing the ability to access all systems at once, due to isolated user interfaces.

Often the importance of DCS/PLC programming is not understood by upper management. However, in reality the PLC programming is often a bottle neck to implement needed functionality in the available time. Therefore, there is a big potential in improving the PLC programming approach.

Operations must provide the biggest effort to handle increased product complexity. [5]

Organization not ready

Current limitations in organizations like widely spread separation between IT and Operations, hinder new approaches to be applied. Software purchasing is often separated in the organization based on requirements and budget allocations. Manufacturing department traditionally invest in hardware and come last in IT investments. [4]

Competitive pressure

In today's given market environment, digitalization is not a choice, but a prerequisite to stay competitive.

Potential of modelling and simulation

Complication-free ramp up during changeover projects, faster time to market, increased collaboration during development, new approaches like virtual stress testing during concept design – are some of the benefits easily accessible through operational virtualization.
To meet tough timing targets for new projects, the engineering team within the industrial operations must be involved early in planned adaptations of the production setup. This early involvement enables operations to prepare, either with flexible production planning, or new innovative approaches in their production-line life cycle management.
Frontloading the possibility to collaborate digitally, e.g. during risk assessments and design reviews, is a key enabler to face today's high rate of changes in production setups with an innovative solution.

Digital Twin

Digital twins are mostly referred to as the virtual replica of planned or existing physical assets, be it a product, a machine, a process, or even an entire factory throughout its whole life cycle. [1] [3]. They contain all the information, data and descriptive and executable models relevant to the management of its physical twin – the original. The behavior of the physical process is represented by simulation models within the digital twin [6]. Emulation is reached when the output of the digital process is identical with the output of the physical process – and therefore predictive.

Modelling

A model is a representation of a planned or existing physical system with its properties and dynamical behavior described in such a way, that it can be interpreted using a computer. [7] The model is tailored towards the systems aspects under investigation and differs from reality only within a certain tolerance. Thus, modelling represents digitization – the recreation of the real world in a digital form. A model is created in order to apply a subsequent, value creating processes to it. The degree of detail can vary, based on requirements from following process steps like assembly checks, function tests, simulations, or emulations. The model represents hardware and software of production setups, modularized and fit with standardized interfaces. Models on its own, are commonly used for assembly checks.

Simulation

Simulation is a virtual experimental study of a systems dynamical behavior, imitated in a computer-model to mimic reality, with the purpose to transfer the findings on to the real system. [7] Thus, a simulator uses a model of a physical process, as well as boundaries to propagate the model through its predefined states, according to given input values. Often used to apply numerous scenarios to identify limitations and iterate the design, based on simulated outcomes e.g. material flow simulations in a packaging line, program run code simulation. Simulations enable various use cases like virtual commissioning, operator training and optimization.

Emulation

Emulation is a very detailed model from a specific hardware in software, to enable software programs written for this specific hardware to run on another system with different hardware. [8] Thus, an emulator, places the model in a realistic, virtual environment, with rules for physics, interfaces, and interaction. The emulated environment allows 1:1 testing and use of the model, which allows a trustworthy feedback, which can be used in new and disruptive ways.
AFRY's "Real-Digital-Twin" Framework combines several Siemens Digital Enterprise tools to create an emulated environment for seamless PLC programming within industrial Automation. Therefore, allowing PLC program code for control and safety systems to run unchanged in both, the emulated and the physical production environment.
This offers the ability to stress test the program code in a trustworthy, virtual environment to increase quality and functionality. The test-based development with a digital twin enables new ways of early collaboration on all levels.

Agile Software development for automation software

Using a simulation as manifold for development and production can help to advance communication between teams, and accelerate verification, especially remotely. [9]
Automation business has huge potential within:

- Standardization and modularization of PLC Code
- Framework application
- Test based development / Standardized stress testing
- Agile PLC SW development process
- Continuous Integration & Continuous Deployment

These approaches have proven to enable faster time to market at a better quality, within the software industry.

This principle is also described in the VDI Guidelines on Virtual Commissioning. [10]

Application of AI within automation

When following structured routines, and standards, like PackML, the software development can benefit from automated stress testing. Artificial Intelligence can be used to identify dead ends in the safety program or optimize OEE by proposing the best set of parameters. [11]
These AI services are nowadays located in a cloud, and can therefore be centrally managed, and used globally.
A recently started research initiative reviews the tool chain used in manufacturing engineering and emphasizes applications of AI. [9]

Application areas for virtual plants

The listed steps from a model, over simulation towards digital twins can be applied in a number of different industry branches, introducing identical benefits:

- Better project control due to increased collaboration and verification
- Unproblematic installation and ramp-up due to virtual integration tests
- Efficient operation and maintenance due to predictive data analytics
- Realistic operator training environment

Examples of successful implementations are:

- Body and White manufacturing – welding robots
- Common manufacturing – conveyer belts, material handling, equipment
- Nuclear industry – Safety Systems
- Water treatment – Process control for water treatment
- Automotive Industry – assembly robots, test systems

Digital Twin in practice

Benefits of virtual plants for commissioning

State of the art commissioning approaches allow to fully stress test and optimize your production process virtually, and trustfully apply the outcome on the physical production setup.

System integrator AFRY developed a workflow and a framework called "Real-Digital-Twin" using Siemens' Digital Enterprise software portfolio, including SIMIT, S7 PLCSIM Advanced, NX MCD with industry standard interfaces.

This workflow maximizes the value of digitalization, as it allows for more parallel collaboration at an earlier stage in production cell commissioning projects. The framework allows for emulated production environments to detect a higher degree of issues early, saving time and money with real world troubleshooting.

The digital twin becomes a digital master, to allow for collaboration with standardized interfaces, accelerating time to market, an allow for application of standardized quality assurance – minimizing downtime and extra workload for troubleshooting.

The "Real Digital Twin" allows to create a 100% signal true emulation of the sensor and actor data to create an early, trusted test bench for software iteration, saving time and money due to elimination of start-up delays and ramp up problems.

Fine adjustment and process improvement happen virtually, are emulated, and tested, and applied to production line.

Reference cases for virtual plants enabled by AFRY's engineering services and Siemens' Digital Enterprise portfolio

Volvo Olofström – Body in White Manufacturing

What

AFRY in Olofström wants to streamline its operations within production line design and commissioning, to have the capability to follow customers' globalization. The challenge is to reduce development and commission lead times in order to match global market launch windows of the automotive industry.

Why

The work is moved from the customer's factory floor to the office environment. By using the right way of working and the right tools. AFRY can verify functionality early and reduce the risk of errors. By adopting and integrating Industry 4.0 as a backbone, AFRY strengthens its competitiveness by adapting to increased complexity requirements.

How

Through development and adaptation of digital twins, using Siemens simulation software like Tecnomatix Process Simulate and Siemens SIMIT. AFRY's automation engineers can frontload testing and accelerate iterative design steps. This save time and cost and increases quality. By adopting this change, they can test before entering the factory floor and become confident that the solutions work as it should.

Value

- Faster time to market
- Higher quality through iterative testing
- Better customer trust through transparency

Alfa Laval – a world leader in heat transfer and fluid handling

What

To Alfa Laval needed to expand and automate its capacity in the production facility in Eskilstuna due to higher market demands. To secure the new production cells functionality, development potential and support ramp up and education AFRY delivers a complete production cell including an emulated "Real Digital Twin" (RDT). [12] [13]

Why

To secure functionality, integration, and safety during commissioning and start of the production cell AFRY uses a Real Digital Twin. By using the RDT, AFRY executed a vFAT (Virtual Factor Acceptance test) to find faults early and ensure fault-free integration during final installation. Efficiency gains are clearly visible when using the emulated digital object and can be tested virtually. The RDT is also the platform for virtual training of production personnel and gives the possibility to trial-run new functions. Applying this structured approach allows the use of AI/ML in the tool chain to quickly find and resolve efficiency drains.

How

AFRY delivers a Real Digital Twin, as Software-as-a-Service, used for commissioning, operation, and maintenance of the physical production cell. Furthermore, this digital twin is used for operator and service technician training. The service includes all equipment to emulate the production cell.

Value

- Reduce cycle time - through virtual benchmarking
- Reduced commissioning time

Bearings manufacturer – Factory Acceptance Test on Digital Twin with remote Hardware in the loop

What

A Grinding machine was scheduled to go through a software upgrade and relocation. The machine was not available for a physical integration test, as it was used in running production. In order to minimize potential risks, shorten the production stop and ramp up time, the integration has been tested virtually with the help of a digital twin of the future production setup. The goal was to test the communication between the cell PLC and machine PLC before the relocation and final site integration test within the new production cell.

Why

The cell was built and ready on site. The grinding machine was connected to the cell and no interface errors were found! This means that the cell ramp-up was instantly.

"If the 4 days of virtual debugging would have been done "as usual", after on-site installation, it would have been taking at least 20 days of planned production time!"

How

AFRY has developed a method and architecture for generating models of virtual objects and connecting them to the virtual commissioning tools. We have set up an architecture with Siemens SIMIT, that connects all programs such as RobotStudio, Siemens PLC, Safety, and all virtual objects in the cell at 100% signal level. When the PLC sends a start signal to an emulated machine in SIMIT, the response of the digital twin is identical to that of the physical machine.
We are also able to trigger various scenarios or errors in SIMIT that cause incorrect signals to be sent, and therefore stress test the different programs. There is also safety logic sequences, logic and timings simulated between PLC, Machines and Robots. We simulate safety with sensors such as light bars and button panels with emergency stops, etc. This virtual world is set up and commissioned visually with HTC Vive PRO in a VR studio.

Value

- Reduced commissioning time
- Limited down time
- Minimized risk

Enabling Portfolio

One example for a digital thread in a manufacturing company

The digital thread of existing products and new developments often starts in a Product Lifecycle Management tool (PLM, e.g. Siemens Teamcenter), which acts as a database for CAD models, PCB schematics, technical specifications, and other documents describing a product. Different design and simulation tools use these digital objects as input, to generate the desired output.
By connecting several simulation tools, a continuous digital representation of the production setup can be created.
The continuous digital thread enables parallel workflows and faster time to market.

A manufacturing setup, can be split into the following levels:

- **Factory level**
- **Line / Cell level**
- **Machine / System level**

Each level has different requirements towards the digital representation, and different purposes and parameters.
Due to this abstraction it is possible to apply simulation tools to drive domain specific values and handle complexity requirements coming from today's markets in an efficient way. [5]
The Following pages describe each of the levels, including expected value creation and matching digitalization tool.

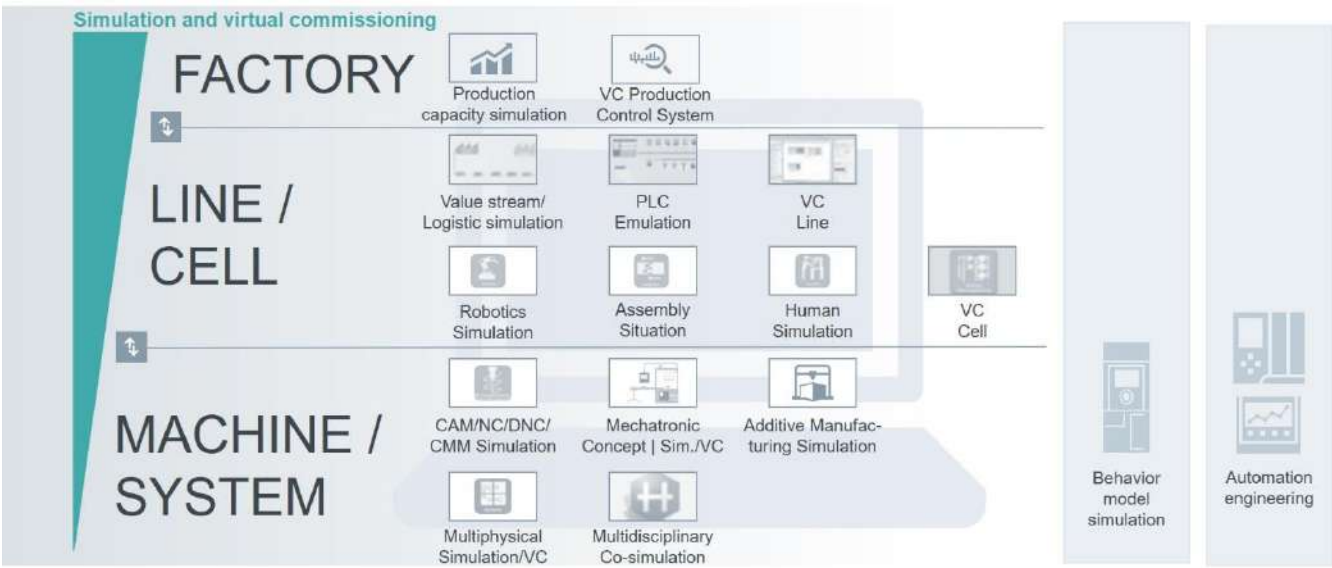

Figure 4 - The different levels require adequate digital representation - Common interfaces connect their output and Input at the level boundaries

Factory / Line level

Data input from product development and product management is used for high-level simulation of the factory setup (Siemens Tecnomatix Plant Simulation). The goal of this simulation is to find the optimal setup of the factory to produce the physical product according to the demand. The simulation environment allows to optimize material flow, resource utilization, logistics, and detect bottle necks. This approach can be applied on the top levels, as defined in ISA 88: Enterprise, Site, Line. The Result is a refined model with optimized parameters for each line.

Tecnomatix Plant Simulation is a user-friendly simulation platform for creating complex systems for material transport via simple drag and drop. In addition, it's possible to evaluate topics like throughput of a production line and sizing of material buffers and warehouses. The connection to a virtual controller like S7-PLCSIM Advanced enables to simulate and optimize different scenarios for the superimposed controlling unit.

Line / Cell level

Using the optimized models for each production line, a more detailed, line-specific, simulation (Siemens Tecnomatix Process Simulate) is possible to iterate through different line setups, avoiding bottlenecks due to blocking or starving. The simulation allows to adapt to cycle times, kinematics, and material handling. All functional blocks are represented through digital objects that represent the physical production equipment. The virtual environment also allows to accurately represent machine behavior to enable virtual stress testing and application of best practices, as well as reinforced machine learning.
The output of this step are digital objects for each cell, which represent a working, and validated, production setup.

Tecnomatix Process Simulate provides the possibility to design the layout of production lines and to validate mechanical sequences. This includes the generation of robot programs and validation of collisions and accessibility of certain points in a space. Together with the automation model it's possible to simulate the PLC code in interplay with robot programs and workflows in the production line.

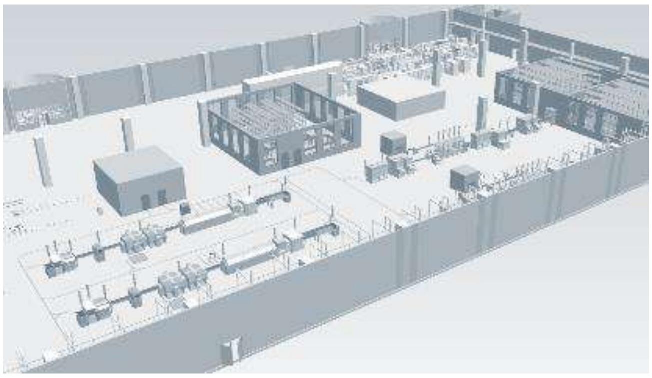

Figure 5 - Tecnomatix Plant Simulation

Figure 6 - Tecnomatix Process Simulate

Machine level

At the lowest level of plant virtualization, specialized machines are simulated using digital controllers, signals, and mechanics. High fidelity simulation models of a machine can be created and used at this level.
The digital twin of the machinery consists of three parts:

- The mechanical simulation and visualization (NX MCD)
- The behavior model of the machine (SIMIT)
- The automation model/simulation (S7-PLCSIM Advanced)

This step allows to ensure reliability, and to include equipment under development to be included in virtual factory acceptance tests.

If there is a requirement to simulate multi-physics, or unique process parameters, then additional models from other simulation tools (e.g. Siemens Simcenter Amesim) can be used and integrated through standardized interfaces.

NX Mechatronics Concept Designer has easy-to-use modelling and simulation which allows you to quickly create and validate alternative design concepts early in the development cycle and to set up a mechanical simulation for virtual commissioning of a machine.

This validation is enabled by the re-use library, from which you can quickly add data to the functional model. This data includes joints, motion, sensors, actuators, collision behavior, and other kinematic and dynamic properties for each component. This allows a physics-based, interactive simulation to verify machine operation. This verification helps you detect and correct errors in the digital model.

The Mechatronics Concept Designer can be used to test machine concepts and by reuse of the machine's CAD data a realistic model can be created and used for virtual commissioning of the machine.

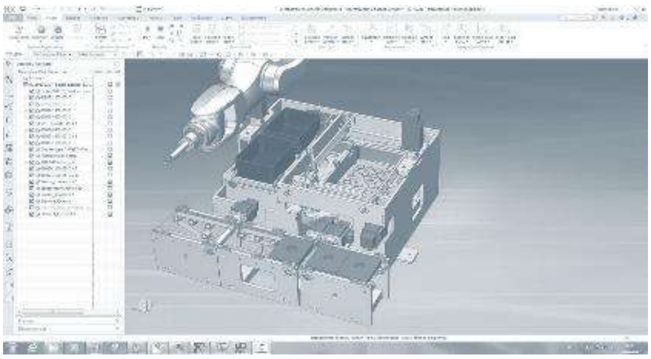

Figure 7 - NX Mechatronics Concept Designer

Simcenter Amesim enables engineers to perform system simulations to evaluate and optimize the performance of mechatronic systems in a virtual environment. This allows to increase productivity of system development processes from the early development phase until the final performance review and validation of the controller.

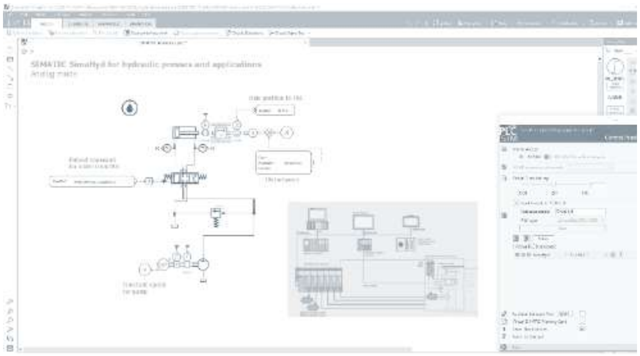

Figure 8 - Simcenter Amesim

Level-independent

The loosely connected digital objects can be further detailed, into a real-time, event based, simulation of interconnected, virtual production cells with 100% identical signals to their physical twins.
Each cell is controlled by a PLC, which is represented by a digital twin. This environment is able to emulate the behavior of upcoming cells down the line, to allow for agile software development and validation with predefined test scenarios and pass/no pass conditions. Even Safety related functions can be verified in the virtual environment as signals are emulated with latency and kinematics are included in the simulation.
As an outcome, this level of simulation allows to run virtual Factory acceptance tests, to frontload decision taking. – At this point, a change in the original product design, can immediately be checked in the virtual production setup.

SIMIT performs simulations for comprehensive tests of automation projects as well as the virtual commissioning of systems, machines, and processes. In addition, the simulation platform can also be used for realistic training environments to train operating personnel.

With SIMIT all relevant automation functions can be tested safely and efficiently before the actual start-up, using the original automation programs. Easy coupling between the simulation and automation environment. The coupling can be done with the real hardware of the automation systems (hardware-in-the-loop) and with the integrated virtual controller or the SIMATIC S7-PLCSIM Advanced and therefore without real hardware (software-in-the-loop). By simply adopting existing planning and engineering data as well as further simulation models, already existing knowledge can be used efficiently for the development of the simulation environment. The integrated project analysis visualizes interfaces, diagrams, model sizes, etc. In addition, SIMIT provides several libraries with industry specific and simulation components.

As seen, SIMIT can optionally be used on each simulation level to enable customer specific use cases. This allows to reuse simulation models on the different levels and hereby the effort of creating the simulations models for each level will be reduced.

Despite that SIMIT offers a broad range of connections to other simulation tools. This makes SIMIT highly versatile regarding the area of use.

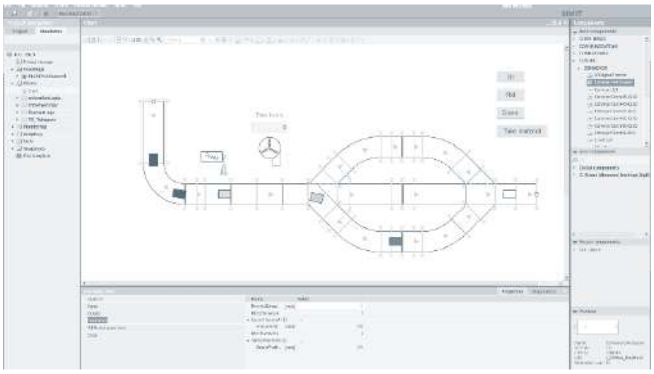

Figure 9 - Siemens SIMIT

SIMATIC S7-PLCSIM Advanced is used to simulate S7-1500 and ET 200SP controllers and to simulate functions in a comprehensive way. Additionally, the virtual controllers can be tested and validated in context with a plant or machine. An extensive API allows the connection to plant and machine simulations (co-simulations).

Similar to SIMIT, S7-PLCSIM Advanced can be used on each simulation level.

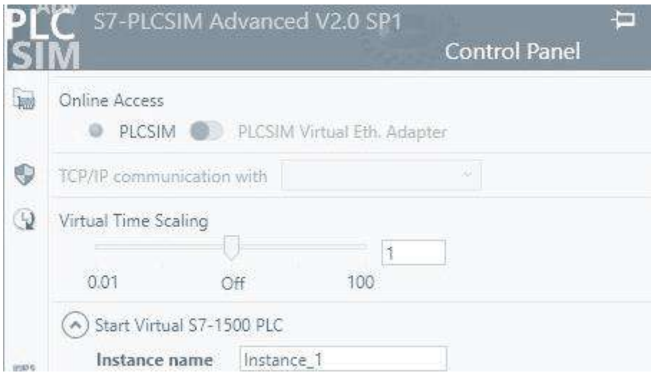

Figure 10 - Siemens S7 PLCSIM Advanced

The Result is a digital twin in three levels, providing virtual environments with different resolutions for different purposes. From factory capacity simulations to troubleshooting on signal level.

Each level provides input parameters to the lower level to create a closed loop. After a successful installation, the continuous improvement starts right away, and with a verified digital twin, all changes can be simulated before implementing.

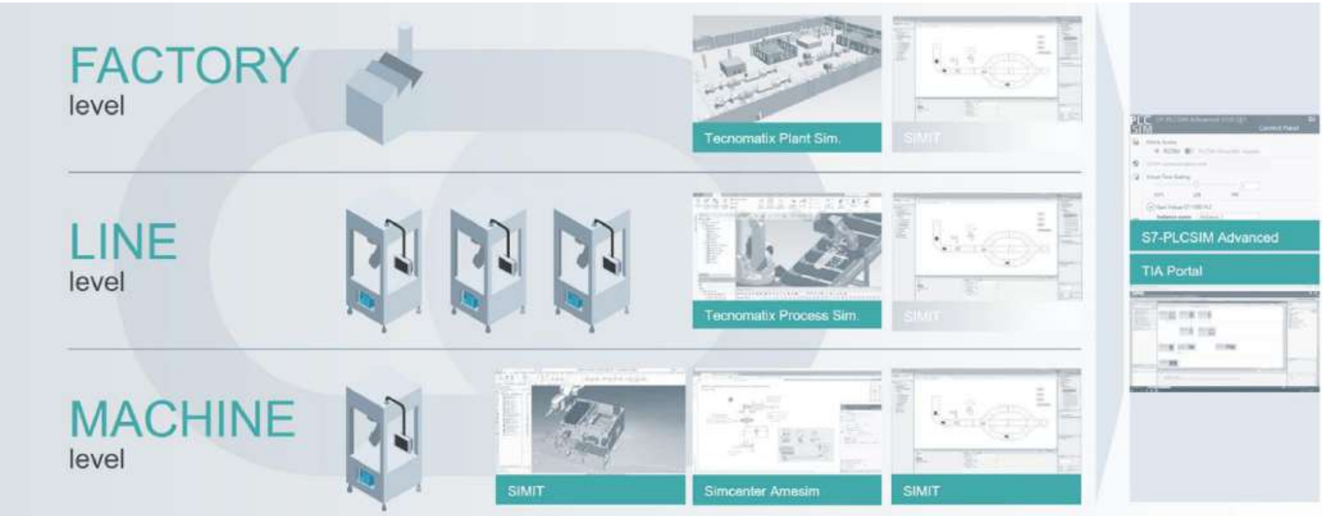

Figure 11 - Modular enabling portfolio of simulation tools to enable customer specific use cases using one or multiple of the listed Siemens tools

Virtual commissioning portfolio interplay

AFRY's "Real Digital Twin" (RDT) framework, is the key component of "Real Virtual Commissioning" and solves problems of traditional department boundaries – sequential execution of work packages, leading to revisions and desynchronization of the workflow.

Applying the RDT Framework allows to work with one common digital twin during design, test, approval, commissioning, and operation of a production cell.

The goal of this concept is – within the cell/station – to emulate the physical process including component signals, so that PLC code approved for the digital twin is also approved for the physical implementation(s).

This allows for parallel workflow with increased collaboration from an early stage, leading to the following benefits:

- Ongoing development can be tested virtually and combined with physical components to create the complete system for communication and signal tests.
- Complete Systems can be reviewed in a virtual Factory Acceptance Test (vFAT) before delivery.
- Creating a standardized, robust test bench to stress test PLC software or other program code in an emulated environment.
- Operational program code can be shared between virtual and physical environment without changes.
- Integration against Parent or child systems can be prepared virtually, and stress tested before implementation in the operation. (e.g. MES – Manufacturing Execution System).
- Allowing standardized Quality Assurance methods.

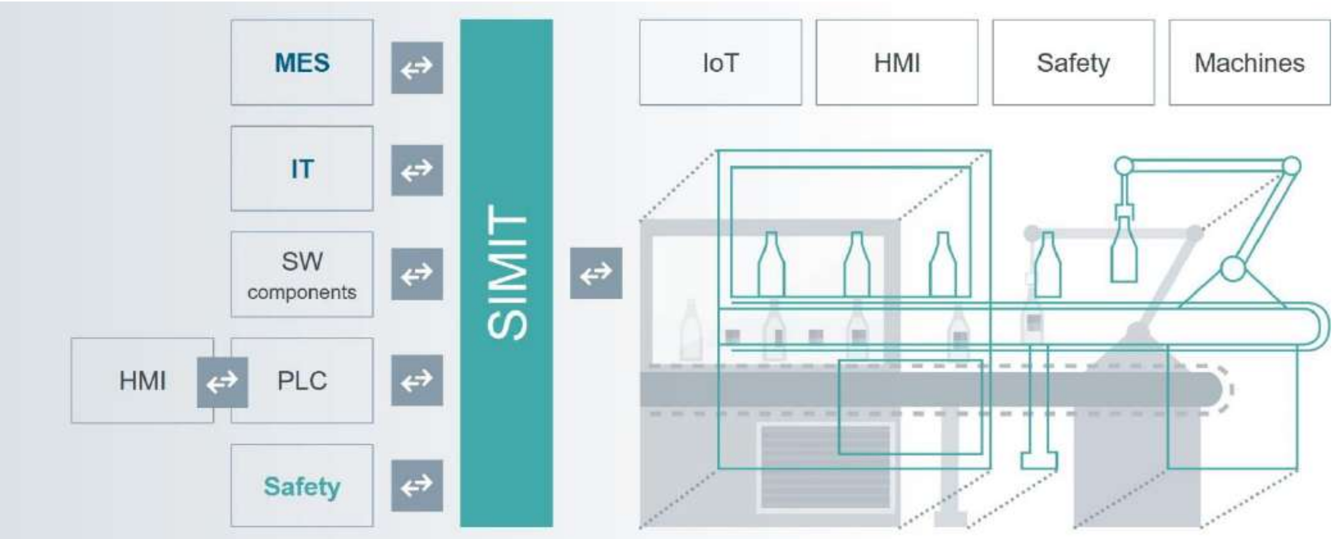

Figure 12 – AFRY's Real Digital Twin architecture using SIMIT as central connection for physical hardware and virtually represented hardware to simulate a cell

Summary and Outlook

Digitization is today a decisive factor for the continued development of industry efficiency. However, the ability of actors to adapt to the new technology differs in order to meet the requirements, ranging from environmental requirements to production and cost requirements.

The industry has an increasingly higher demand on flexibility, quality, and cost efficiency.

The ability to flexibly adapt to demand and supply changes, analyses outcomes and proactively work with AI / Machine Learning is crucial to continuously improve competitiveness.

It is not only the adaptation of the technology that must be handled, but also changes in how the organization work together. Processes and responsibilities will quickly evolve towards a more agile way of working where change is the natural state. The approach to meet this challenge is an iterative model creation and testing, to quickly evolve new functionalities.

The technologies described in this whitepaper, among other things, together with an adaptive and proactive organization, are the competitive differences that determine who will be the winner in the future.

This calls for actions – and the time is now.

Acknowledgements

Siemens is a global powerhouse focusing on the areas of electrification, automation, and digitalization. One of the world's largest producers of energy-efficient, resource-saving technologies, Siemens is a leading supplier of systems for power generation and transmission as well as medical diagnosis. In infrastructure and industry solutions the company plays a pioneering role.

AFRY is an international engineering, design, and advisory company. We support our clients to progress in sustainability and digitalization. We are 17,000 devoted experts within the fields of infrastructure, industry, and energy, operating across the world to create sustainable solutions for future generations. Making Future

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References

[1] R. Rosen, "Simulation & Digital Twin in 2030 - A technology outlook, White Paper on experts' predictions.," 2020. [Online]. Available: https://new.siemens.com/global/en/company/stories/research-technologies/digitaltwin/outlook2030.html.

[2] Deutschen Akademie der Technikwissenschaften, "Acatech - Industry 4.0 Maturity Index," March 2018. [Online]. Available: https://www.acatech.de/wp-content/uploads/2018/03/acatech_STUDIE_Maturity_Index_eng_WEB.pdf.

[3] L. Bruckner, M. Oppelt, L. Urbas and M. Barth, "The current and future use of simulation in discrete and process industries - Results of a global online survey. White Paper.," September 2020. [Online]. Available: https://www.researchgate.net/publication/344269523_The_current_and_future_use_of_simulation_in_discrete_and_process_industries_-_Results_of_a_global_online_survey_September_2020.

[4] VINNOVA, "Digitalisering – mer än teknik (Digitalization - more than technology)," April 2018. [Online]. Available: https://www.vinnova.se/publikationer/digitalisering--mer-an-teknik/.

[5] "Productcomplexity Management," [Online]. Available: https://www1.unisg.ch/www/edis.nsf/SysLkpByIdentifier/4148/$FILE/dis4148.pdf.

[6] M. C. R. D. E. G. C. K. J. L. a. L. W. M. Shafto, "Modeling, Simulation, Information Technology & Processing Roadmap. Technology Area 11. Edited by National Aeronautics and Space Administration.," 2012. [Online].

[7] Verein Deutscher Ingenieure e.V., "Simulation of systems in materials handling, logistics and production - Fundamentals," [Online]. Available: https://www.vdi.de/richtlinien/details/vdi-3633-blatt-1-simulation-von-logistik-materialfluss-und-produktionssystemen-grundlagen.

[8] J. H. Saltzer and F. Kaashoek, Principles of computer system design. An introduction., Burlington, MA: Morgan Kaufmann, 2009.

[9] ITEA, "Artificial Intelligence supported Tool Chain in Manufacturing Engineering," [Online]. Available: https://itea3.org/project/aitoc.html.

[10] Verein Deutscher Ingenieure e.V., "Virtual commissioning - Model types and glossary," [Online]. Available: https://www.vdi.de/richtlinien/details/vdivde-3693-blatt-1-virtuelle-inbetriebnahme-modellarten-und-glossar .

[11] OMAC, "PackML Unit Machine Implementation Guide," November 2016. [Online]. Available: http://omac.org/wp-content/uploads/2016/11/PackML_Unit_Machine_Implementation_Guide-V1-00.pdf.

[12] [Online]. Available: https://afry.com/en/newsroom/press-releases/alfa-laval-takes-next-step-towards-industry-40-afry.

[13] [Online]. Available: https://www.alfalaval.com/media/news/investors/2020/alfa-laval-takes-the-next-step-towards-industry-4-0-through-digital-operations-development/.

[14] Siemens , "Digital Enterprise," [Online]. Available: www.siemens.com/DigitalEnterprise/.