

Business Process Redesign for IT-OT Convergence in Industry 4.0



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Abstract

The convergence of Information Technology (IT) and Operational Technology (OT) presents operational challenges in industrial automation, particularly in cloud-native environments of Industry 4.0. This case study examines the process of systematically redesigning business processes for effective convergence of IT and OT in a growing company. To address the identified problem, we adopt a systems engineering methodology and propose an Industrial Business Process Twin (IBPT)-based solution. The solution comprises standardized, scalable, and traceable layers that coordinate the IT-OT convergence in operations that were previously siloed. Specifically, we apply Model-Based Systems Engineering (MBSE) techniques to visualize the architecture of specific user cases for the redesign workflow, including integration, communication, technical verification, and validation within the company. The solution is validated at the end.

Keywords

IT-OT Convergence, Industry 4.0, Business Process, Industrial Business Process Twin, RAMI4.0, Systems engineering, MBSE.

Introduction

Background

The Third Industrial Revolution (Industry 3.0)

introduced automation to manufacturing through the use of electronics and programmable logic controllers. While these technologies increased production efficiency, they typically operated in

isolated environments, with limited integration between functions. Industry 4.0 tackles these challenges via the convergence of Information Technology (IT) systems, such as cloud computing, Artificial Intelligence (AI), and advanced analytics, with Operational Technology (OT) systems, including industrial sensors, actuators, and control devices (Kagermann et al., 2013). IT-OT convergence supports real-time decision-making and operational agility in industrial automation (Shilenge and Telukdarie, 2022).

However, implementing IT-OT convergence remains challenging due to fundamental differences in workflow practices and verification and validation (V&V) requirements across IT and OT domains. IT systems prioritize rapid development, continuous integration, and continuous delivery (CI/CD) pipelines, and cloud-native deployment strategies. In contrast, OT systems emphasize deterministic behavior, reliability, safety, and rigorous verification and validation (V&V) processes (Schäfer et al., 2024). These contrasting requirements frequently result in separate workflows, communication gaps, duplicated technical V&V efforts, and inconsistent quality assurance across the converged environment (Schäfer et al., 2024).

The case examined in this study is an industrial-automation company offering a software-defined control platform. Like many firms operating at the

intersection of software and industrial control, the company faces typical IT/OT coordination challenges widely reflected in the literature—such as fragmented workflows, duplicated quality-assurance activities, and limited cross-domain visibility. As the organization prepares to scale, these issues highlight the need for more structured and integrated processes to ensure consistent verification and validation (V&V), reduce cognitive load across teams, and support operational efficiency. The study explores how systematic business-process redesign can address these challenges and enable more coherent IT-OT convergence.

Research Question

In view of scaling operations for IT-OT convergence, our primary research question is, "How to systematically redesign business processes for IT-OT convergence to improve operational efficiency?"

By employing a systems engineering methodology, we develop a structured research design for this case study. The study aims to illustrate the practical application of existing approaches and techniques to facilitate IT-OT convergence within the specific industrial automation contexts.

Literature Review

This section reviews the state of the art related to IT-OT convergence from an operational perspective and then presents the applied methodologies and techniques of this study, including systems engineering methodologies and Model-Based Systems Engineering (MBSE). We highlighted the combined application through the Industrial Business Process Twin (IBPT) concept, supported by Model-Based Systems Engineering (MBSE) and structured using RAMI 4.0, to address our targeted problem.

IT–OT Convergence in Industry 4.0

Industry 4.0 represents a shift toward integrated and intelligent manufacturing, combining Information Technology (IT), such as enterprise software, analytics, and cloud computing, and Operational Technology (OT), including sensors, actuators, and industrial control systems. Traditionally,

IT and OT have operated separately, causing data integration and coordination challenges due to distinct protocols, life cycles, and stakeholders (Madni and Sievers, 2018). Industry 4.0 addresses these challenges by proposing design principles that focus on this convergence.

Hermann et al. (2016) identified the four key principles of IT-OT Convergence in Industry 4.0: interconnection, information transparency, technical assistance, and decentralized decision-making. Interconnection refers to the process of networking all entities (people, machines, sensors) and enabling them to communicate (Hermann et al., 2016). Information transparency means that raw data from OT devices are transformed into meaningful information for IT systems, creating virtual plant models and real-time analytics. Technical assistance encompasses digital systems that aid humans through visualization and decision support, as well as provide physical assistance in tasks via robotics. Decentralized decisions indicate that cyber-physical systems can autonomously make specific decisions, with IT algorithms directly launching OT actions when appropriate (Hermann et al., 2016). Successful convergence requires structured, model-driven solutions rather than ad hoc integration, facilitating real-time data sharing and integrated V&V processes (Schäfer et al., 2024). The digital twin concept has emerged as a promising approach, providing virtual replicas of physical assets and processes to enhance visibility and integration across domains.

Business Processes Digitalization

The digitalization of business processes involves representing workflows and interactions in machine-readable and software-executable formats, thereby facilitating seamless integration with operational systems. This method ensures immediate synchronization between physical operations and enterprise systems (Fornari et al., 2024). To specifically address IT-OT convergence challenges, Schäfer et al. (2024) introduced the Industrial Business Process Twin (IBPT), a digital twin explicitly designed for business process integration. IBPT mirrors business processes, continuously synchronizing between IT and OT activities. Instead of direct interaction, IT and OT communicate via the IBPT, ensuring coherent integration and consistent V&V. As such, IBPT not only can

decouple and coordinate IT-OT convergence, but also can help reduce integration complexity and enhance operational scalability. This decoupling enables methods and analyses from the IT world to be applied to the twin, indirectly affecting the OT world, and for data from the OT world to be fed into IT processes through the twin in a coherent manner. This characteristic directly aligns with the identified operational needs of the case company, as previously highlighted.

In addition to integration, business process digitalization through IBPT facilitates advanced capabilities that align with Industry 4.0 objectives. For instance, the IBPT enables information transparency by integrating real-time data into business-level process intelligence. It also supports decentralized decision-making: autonomous algorithms can run on the twin to optimize or adjust the process flow, then implement changes on physical equipment through the OT interfaces of the twin. Because the twin is continually updated with live data, it provides a platform for analysis, simulation, and even control. What-if scenarios or optimizations can be tested virtually on the IBPT before being deployed to the main process. This is especially valuable for V&V of process changes; engineers can validate a new workflow (Fornari et al., 2024).

RAMI 4.0 as a Reference Framework for Systems Integration

The Reference Architecture Model for Industry 4.0 (RAMI 4.0) is a relevant framework for tackling an organization’s operational complexity in Industry 4.0 systems, i.e., IT-OT convergence in our study (Adolphs et al., 2015; Shirbazo et al., 2025). As shown in Figure 1, RAMI 4.0 provides a three-dimensional model integrating hierarchical layers, life cycle phases, and system layers (Adolphs et al., 2015; Shirbazo et al., 2025).

- Hierarchy Levels (Z-axis) represent different aggregation levels of equipment and control, based on the automation pyramid (Product, Field Device, Control Device, Station, Enterprise, up to the Connected World). This axis ensures that integration is considered from the lowest level up to the comprehensive enterprise and even the inter-enterprise level.

- Life Cycle and Value Stream (Y-axis) represent the life cycle phases of assets and their value stream steps, typically split into Type (development phase of a product or system type) and Instance (operational phase of an individual instance). This axis highlights the importance of considering both design-time and run-time aspects of systems.
- System Layers (X-axis) represent different aspects or perspectives of an Industry 4.0 component. The standard defines six layers: Asset, Integration, Communication, Information, Functional, and Business. The Asset layer represents the physical entity (machine) or logical entity (software process). Above it, the Integration layer abstracts the asset via digital representation. The Communication layer covers protocols and connectivity for data exchange. The Information layer includes data models and concepts that describe the asset. The Functional layer describes functions, services, or behaviors of the asset. Finally, the Business layer represents business process context and rules involving the asset (Adolphs et al., 2015).

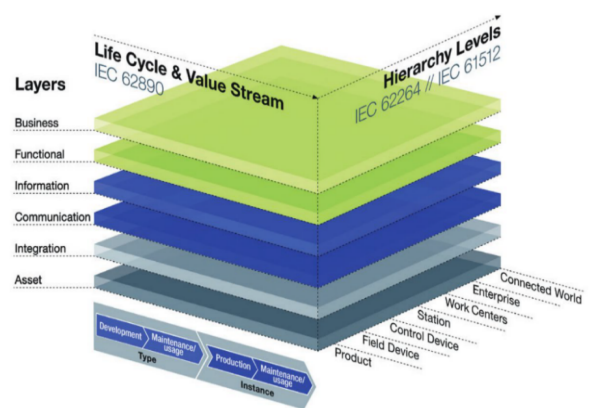


Figure 1. Reference Architecture Model 4.0 (Adolphs et al., 2015)

By combining these three dimensions, RAMI 4.0 provides a holistic map to locate functions or components of an Industry 4.0 solution (Adolphs et al., 2015). The adoption of RAMI 4.0 provides structural clarity and comprehensive guidance on integration for IT-OT convergence. For instance, the application of RAMI 4.0 helps systematically map a customized IBPT solution for each layer, ensuring it comprehensively addresses all essential integration aspects. RAMI layers can help clearly illustrate how IBPT coordinates tasks across IT-OT boundaries and ensures

comprehensive, consistent V&V from high-level business goals down to operational processes.

The IBPT solution, structured according to RAMI 4.0, involves stakeholders and subsystems across multiple layers of business processes. This complexity underscores the need for a suitable methodology and supporting techniques to effectively manage the design and integration of the system.

(Model-Based) Systems Engineering

Systems Engineering (SE) is an interdisciplinary methodology that helps design, integrate, and manage complex systems throughout their entire life cycles. Systems engineering emphasizes a structured problem-solving approach to stakeholder identification, elicitation of needs, and formal requirement specification, coupled with rigorous verification and validation (V&V) to ensure solutions are both robust and manageable (INCOSE, 2007). Model-Based Systems Engineering (MBSE) enhances the SE approach by using formal, integrated modeling techniques to capture system requirements, behaviors, architectures, and V&V activities (Estefan, 2007). MBSE is known as “the formalized application of modeling to support system requirements, design, analysis, V&V activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases” (INCOSE, 2007, p7). It helps early detection of inconsistencies, providing traceability and coherence across various system components. This approach is highly relevant for IT–OT convergence, as it facilitates a unified representation of systems that have traditionally been engineered separately (Madni and Sievers, 2018). For instance, MBSE can support the presentation and management of the IBPT and its operating environment. The benefit of applying MBSE in process integration is the early and continuous V&V through simulation and model analysis. While IBPT directly addresses the convergence and V&V challenges identified in stakeholder interviews by providing a scalable, traceable, and comprehensive integration approach, MBSE ensures rigorous modeling, clear communication, and early V&V. In this way, changes in one domain (either IT or OT) can remain synchronized with the other for improved consistency and less integration burden (Madni and Sievers, 2018). The

generated model-based solutions can be subjected to formal checks, simulation, or execution in a virtual environment long before actual deployment. MBSE provides the methodological framework for building and maintaining the complex models that form an IT–OT convergent system (Friedenthal et al., 2014).

Data and Methods

This study employs a qualitative research method—a single case study. This method is especially effective for in-depth study, capturing the complexities of organizational processes, stakeholder perspectives, and the nuanced dynamics within a specific context (Yin, 2017). The research collaboration with the case company allows iterative insights gathering and progressive refinement of solutions. This study’s approach integrated a literature review with multiple rounds of stakeholder interviews and detailed process analysis to develop a comprehensive solution.

Research design. The study is conducted based on the systems engineering methodology. Figure 2 illustrates this research design. It begins with problem identification and is followed by a literature review. The research problem is derived from preliminary stakeholder input regarding the company challenge, which guides the literature review and subsequent phases. Based on real-life data, we conduct stakeholder identification and elicit their needs, as well as analyze the existing “As-Is” business processes and the envisioned “To-Be” business process scenario. Insights from these stages informed the conceptualization of the solution development, which was subsequently validated by key stakeholders.

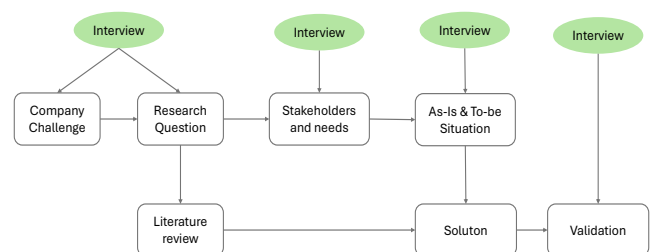


Figure 2. Research Design

Data Collection

We collected firsthand data through semi-structured interviews and second-hand data from the

company's internal documentation for IT and OT operations. Interviewees were carefully selected based on their roles and direct involvement with the IT-OT convergence. These stakeholders represented a comprehensive cross-section of the company's operational and strategic landscape, ensuring that the collected data reflected diverse perspectives necessary for solution development.

We conducted three rounds of interviews. The first round of interviews consists of an informal discussion with senior management on-site and a follow-up online meeting. The aim was to gain an initial understanding of the company's challenge and then validate the research problem. The second and third rounds consist of semi-structured online interviews with all accessible stakeholders in the company. The second round aims to collect data for identifying stakeholders and their specific operational and strategic needs in the operational convergence of IT and OT. The third round is to understand the current business processes and their envisioned future state of IT-OT convergence. The last round of interviews is conducted online with selected experts in the company for solution validation.

Table 1 summarizes the interview rounds, participants, and the purpose of each round of interview.

Type	Participants	Purpose
1 1-to-1 Informal Interview	Leadership stakeholders	Understand the problem context, Validate the research problem.
2 1-to-1 Semi-structured Interview	Leadership & engineering stakeholders	Identify key IT and OT stakeholders and their needs.
3 1-to-1 Semi-structured Interview	Leadership, engineering, & customer-facing stakeholders	Identify the As-is situation and To-be situation
4 Group interview	Leadership, engineering, & customer-facing stakeholders	Validate the proposed solution.

Table 1. Interview, Type and Purpose

Case Analysis

Stakeholder Analysis

Based on the second round of interviews, we identify the key stakeholders for the operational convergence of IT and OT in the case company.

Table 2 summarizes the identified stakeholders, the responsibilities of their roles and their high-level needs.

Stakeholder	Role	High-Level Needs
Leadership stakeholders	Strategic direction, organizational decision-making	<ul style="list-style-type: none"> Operational scalability and traceability Clear, unified processes that support IT-OT coordination
Engineering Leadership	Technical development, systems integration, & testing oversight	<ul style="list-style-type: none"> Unified and consistent QA/V&V practices Streamlined coordination across technical workflows Reduced cognitive load through clearer interfaces and processes
Product Leadership	Product strategy, prioritization, & roadmap alignment	<ul style="list-style-type: none"> Balanced innovation and reliability Structured processes for feature evaluation and prioritization Cross-team knowledge transfer
Customer-facing stakeholders	Customer relations, onboarding, & communication	<ul style="list-style-type: none"> Clear external communication and buyer assurance Transparent explanation of integration and process reliability Alignment between technical processes and customer expectations

Table 2. Stakeholders, Responsibilities and High-Level Needs

Each stakeholder from different roles represents distinct yet interconnected insights into the need for better business processes based on the current operations of IT-OT convergence. and future improvement requirements.

- Leadership stakeholders emphasized high-level organizational needs such as maintaining agility during growth, ensuring that

operational processes remain traceable and efficient, and fostering coherent coordination between IT and OT activities. They highlighted the importance of scalable processes that support consistent quality and alignment with long-term business objectives.

- Engineering leadership noted the need to reduce cognitive load and fragmentation across technical workflows. Their priorities centered on establishing clearer coordination mechanisms between IT- and OT-related tasks, implementing more unified and consistent QA/V&V practices, and improving cross-team knowledge transfer to avoid bottlenecks and redundant work.
- Product leadership stressed the importance of balancing innovation with reliability. They expressed the need for structured decision-making processes, clearer prioritization frameworks, and mechanisms that support traceability of changes throughout the development lifecycle. They also emphasized the value of consistent knowledge-sharing practices across teams.
- Customer-facing stakeholders highlighted the importance of providing clear, consistent communication to external users, especially regarding the reliability, security, and integration of IT-OT processes. Their needs focused on buyer assurance, transparent explanation of processes, and embedding technical validation practices into customer-oriented workflows.

Together, these perspectives illustrate the broad, organization-wide need for more structured, scalable, and unified IT-OT coordination processes.

‘As-is’ Situation

Based on stakeholder interviews, we found the company has employed an agile business process model, using iterative methods such as sprints and retrospectives. These agile practices enable rapid product development cycles, flexibility, and quick adaptation to customer needs. Both IT and OT teams are highly skilled and capable of effective individual contributions, enabling the company to deliver successful outcomes to existing customers.

However, the company currently has separate workflows for IT and OT domains, with partially structured interactions. IT teams manage development through rapid iterations, automated testing, and continuous integration and delivery (CI/CD) pipelines. Conversely, the OT teams conduct simulations, test scenarios, and manual V&V in a rigorous yet static manner due to the safety-critical nature of their tasks.

As is common in many organizations working with both software-driven functions and industrial control activities, IT-related and OT-related tasks tend to operate through parallel processes, each with its own pace, tools, and validation routines. These patterns reflect typical characteristics noted in the literature on early-stage IT-OT convergence, where coordination often occurs through informal mechanisms and where domain-specific testing practices evolve independently. Additionally, several operational routines—such as onboarding of new personnel, documentation practices, and customer communication—are being formalized, which is also typical for organizations scaling their processes. Prototype-driven validation is frequently used to test new functionalities before wider deployment, reflecting industry-standard caution when introducing new capabilities in converged IT-OT environments.

‘To-be’ Situation

To meet the identified needs for future growth, the stakeholders pointed to the desired future state, focusing on structured and scalable business processes for IT-OT convergence. The primary objectives are to enhance operational coordination between the IT and OT domains, reduce cognitive load, formalize internal communication, and streamline V&V and deployment procedures. Specifically, stakeholders identified the following five critical process improvement areas:

1. **Traceable workflow and V&V checkpoints:** To implement structured checkpoints at key phases of the development lifecycle, where IT and OT teams formally coordinate, verify, and validate outcomes together. This would ensure that both domains consistently meet quality requirements and maintain a shared definition of completion.
2. **Formal knowledge transfer and onboarding mechanisms:** To establish documented

processes and guidelines to ensure smooth knowledge sharing across teams. Formal onboarding procedures will reduce bottlenecks and dependency on individual team members, enhancing operational scalability.

3. **Unified QA process:** To develop a unified QA framework integrating automated IT's V&V with rigorous OT testing. This process should include traceability across requirements, test scenarios, and outcomes to ensure reliability across customer deployments.
4. **Clear external communication strategies:** To provide structured and reusable customer-facing materials explaining the platform's integrated nature, cybersecurity measures, and operational benefits. Addressing customer concerns proactively will facilitate quicker adoption and increased trust in the existing solution.
5. **Balance between innovation and reliability:** To establish a robust yet agile V&V environment to test innovative features safely. Utilizing early-stage virtual simulations and prototyping techniques, such as digital twins, will help strike a balance between flexibility and reliability.

In summary, these proposed improvements aim to evolve the current agile and informal approach into a structured, systematic, and scalable operational model that can effectively support future growth. At this stage, the desired solution remains a black box. We will present the proposed solution in the next section.

Proposed Solution

Based on the literature review and the insights from the case analysis, we propose the following set of solutions. It consists of a high-level architecture that adapts IBPT into the operational convergence of IT and OT under the guidance of RAM 4.0. Furthermore, we utilize MBSE to model and present the specific use case in an architectural view, thereby addressing the most desired stakeholder needs regarding communication and V&V for IT-OT convergence.

Adaptation of Industrial Business Process Twin

The decision to adopt the Industrial Business Process Twin (IBPT) as the basis for the operational convergence of IT-OT is aligned with the stakeholder needs and fits into the desired situation. IBPT explicitly addresses these challenges by providing a unified, scalable, model-based coordination approach that integrates V&V logic, ensures traceability, and facilitates cross-domain collaboration (Schäfer et al., 2024). Specifically, IBPT offers a digital representation of the company's key business processes, from client onboarding to software-based automation deployments within the operational environment. Through IBPT, IT developers and OT engineers collaboratively manage and synchronize workflows, interactions, and V&V activities within a shared digital platform. For example, IT developers defining cloud services and OT engineers working on software-based automation routines can both interact through standardized interfaces defined in IBPT. This significantly reduces ad hoc interactions, duplicated V&V efforts, and cognitive overload. To demonstrate how IBPT directly aligns with Industry 4.0 principles, Table 3 below summarizes its feasible adaptation under the guidance of RAMI 4.0 (Hermann et al., 2016).

Industry4.0 Principle	Adaptation of IBPT
Interconnection	IBPT connects IT systems with OT systems (software-based automation , sensors) using standardized interfaces and protocols.
Information Transparency	Real-time operational data from OT devices is collected, aggregated, and displayed within the IBPT, enabling all stakeholders to access up-to-date information.
Decentralized Decision-Making	The IBPT allows cloud-based analytics and business logic to interact with operational data directly, enabling autonomous decisions without relying on centralized control.
Technical Assistance	IBPT acts as a virtual sandbox environment where AI-driven diagnostics, simulations, and optimizations can occur safely and continuously without impacting live operations.

Table 3. Alignment of IBPT-based Solution with Industry 4.0 Design Principles

Furthermore, we proposed and designed the high-level architecture for how IBPT will be adapted in the operational convergence of IT and OT. We

conceptualize the sequential three-phase structured approach with a feedback loop from streamlining the architecture to operational use of the solution, shown in Figure 3.

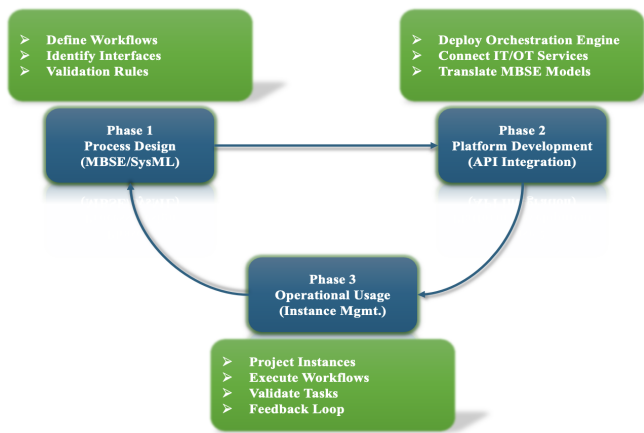


Figure 3. Adaptation Phases of the IBPT in the Case Study

The First Phase

Stakeholders can identify the specific workflow to be redesigned using IBPT for IT-OT convergence. For instance, engineers can define workflows such as customer onboarding, software-based automation deployments, and embedded V&V checkpoints. Specifically, standardized API interfaces will be clearly defined to ensure interoperability between IT and OT domains. In this phase, we can use the RAMI-aligned MBSE tool to create explicit, comprehensive digital models of critical business workflows and V&V rules. By aligning these SysML models explicitly with RAMI 4.0, the case company can ensure architectural consistency and compliance with Industry 4.0 standards.

The Second Phase

It involves translating the designed SysML models into executable workflows. These workflows operate on a secure orchestration layer that manages process execution in a controlled and traceable manner. Runtime instances are created and monitored via standard interfaces, allowing the modeled logic to be executed consistently and safely across technical environments. In this way, the IBPT becomes operational by connecting modelled workflows to the broader system architecture, enabling real-time coordination and

monitoring without exposing domain-specific implementation details.

The Third Phase

In the final operational deployment phase, the company creates project-specific IBPT instances that automatically assign tasks, enforce V&V checkpoints, and continuously monitor outcomes. The IBPT actively provides feedback on process performance, immediately identifying any deviations or V&V failures. For instance, if a V&V step, such as "Validate PLC Logic," fails, the IBPT can be designed to immediately stop the process and alert responsible teams and provide root-cause data. This continuous, iterative refinement ensures that the company's business processes remain agile, scalable, and responsive to real-world feedback, significantly enhancing operational efficiency and traceability.

By explicitly addressing the stakeholders' needs, such as reliability, traceability, unified V&V, and scalable coordination, IBPT serves as a robust solution directly aligned with the company's strategic growth, ensuring an operationally efficient convergence of IT and OT (Fornari et al., 2024). The following sub-sections will detail the system's high-level architecture for each phase of the proposed approach.

Structuring IBPT with RAMI 4.0

Structuring the desired IBPT solution to the RAMI 4.0 (Phase 1, Figure 3) provides a comprehensive architectural view of the company's overall business process, ensuring consistent integration across multiple layers, from technical implementation to strategic business outcomes. As aforementioned in the literature review, RAMI 4.0 provides a structured reference model that addresses integration across the Asset, Integration, Communication, Information, Functional, and Business layers. Initially, we customized the RAMI 4.0 for the case company, explicitly mapping each RAMI layer to relevant IBPT components for a holistic understanding of IT-OT convergence across operational practices.

- Asset Layer. It represents the software-based automation instances, accurately reflecting

states without changing core control logic. This digital mirroring ensures system stability and maintains original OT functions.

- Integration Layer. It employs structured APIs to facilitate interactions between software-based automation runtimes and the IBPT. This structured containerization addresses the company’s need for agile deployment and reliable scalability.
- Communication Layer. Standardized communication protocols securely and consistently exchange data between cloud services (IT) and control logic components (OT). This layer directly addresses the company’s challenge of separated interactions and enhances interoperability.
- Information Layer. It implements semantic data models that encompass system states, V&V outcomes, and KPIs, enabling stakeholders to access transparent and interpretable operational data. This directly meets the company’s requirement for enhanced information transparency and decision support.
- Functional Layer. It executes defined workflow logic captured in SysML models. Each task, such as "Execute PLC logic to initiate sensor feedback," is executed strictly in accordance with modeled specifications, significantly improving traceability and operational efficiency.
- Business Layer. It ensures alignment of operational outcomes with strategic goals and service-level agreements (SLAs). IBPT supports the explicit tracking of deployment KPIs and customer-oriented success criteria, directly aligning with business objectives identified by leadership and customer-facing stakeholders.

Figure 4 visually illustrates how IBPT operates across these distinct yet interconnected layers. Vertically, the model illustrates IBPT functionalities spanning from Asset to Business layers (strategic deployment goals and KPIs). Horizontally, the model aligns the company's operations along two RAMI hierarchy levels—Enterprise, representing cloud services and business applications such as CI/CD pipelines and dashboards, and Station

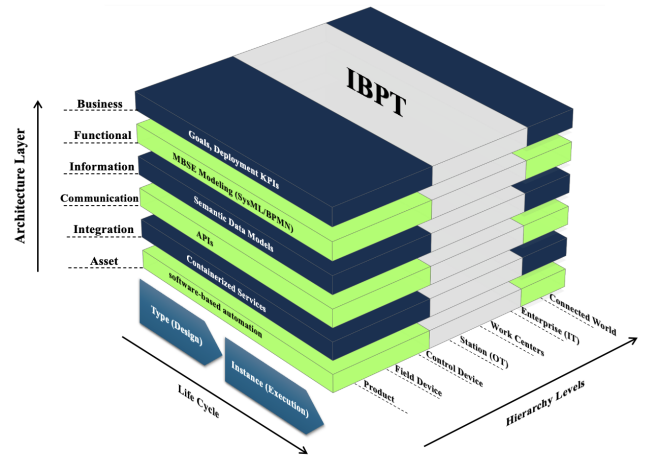


Figure 4. The customized RAMI 4.0 with IBPT (Adapted from Adolphs et al., 2015)

—encapsulating OT control logic and software-based automation. The lifecycle dimension (Type and Instance) ensures clear separation between design-time model definitions (MBSE SysML workflows and APIs) and runtime operational instances (actual customer deployments), enabling continuous feedback and iterative refinement. Table 4 summarizes the roles of IBPT Components for each of the RAMI 4.0.

RAMI Layer	IBPT’s Role
Asset	Reflects software-based automation states without changing the core control logic.
Integration	Uses structured APIs and containerized services to manage interactions with software-based automation runtimes.
Communication	Employs standardized protocols to facilitate reliable and secure data exchange between IT - and OT (control logic) domains.
Information	Semantic data models represent system states, V&V outcomes, and KPIs, providing transparency and interpretability.
Functional	Executes defined workflow logic from SysML models. Each step (such as “Execute software-based automation logic” or “Validate sensor feedback”) runs as specified in the model.
Business	Ensures operational outcomes align with strategic goals, tracking customer KPIs and service-level agreements.

Table 4. Mapping the Role of IBPT Components to RAMI 4.0 Layers

Besides the relevance to the cloud-based operational environment of the case company, the

customized RAM 4.0 with IBPT also provides a roadmap to address the specific integration and scalability challenges identified by stakeholders, such as communication and V&V in this case study. We exemplify the architecture design of the IBPT solutions for the integration layer (Phase 1, high-level architecture) and then translate the high-level solution to the communication layer (Phase 2, detailed system architecture) in the next two subsections.

Visualization of High-level Architecture (Phase 1)

We further adopt MBSE with SysML in a RAMI-aligned modeling environment (Phase 1). The high-level system architecture diagram (Figure 5) illustrates that IBPT functions as the central integrative component between the operational processes of IT and OT systems.

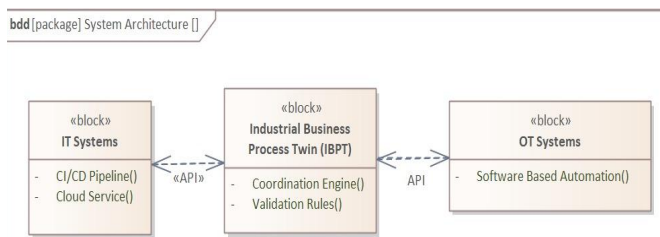


Figure 5. System Architecture of IBPT Integrating IT and OT Systems)

This design explicitly addresses previously identified integration gaps by ensuring that interactions between IT deployment and monitoring tools (such as build/deployment pipelines and operational dashboards) and OT elements, particularly the software-based automation, are strictly mediated through standardized APIs via the IBPT’s Coordination Engine and V&V Rules. By doing so, the IBPT significantly reduces the cognitive load on developers and engineers, removing the need for ad hoc integrations and providing clear, formalized coordination points. This aligns with stakeholders’ needs for enhanced traceability, clarity of integration, and synchronized checkpoints.

Translating MBSE Models for Connecting IT & OT Services (Phase 2)

To clarify integration at the operational level, a detailed communication layer diagram was developed (Figure 6). This diagram explicitly models interactions between critical IT components (CI/CD Pipeline, Dashboards), the IBPT itself, and OT components (software-based automation, Cloud Monitoring). Communication between these systems is standardized, utilizing APIs for IT communication and protocols for OT communication, ensuring secure and reliable data exchange. For instance, the CI/CD Pipeline submits "Deployment Requests" to the IBPT, which then translates these into actionable instructions communicated to the software-based automation. Execution metrics and feedback from OT operations are relayed back to the IBPT, providing real-time performance data visible on the Cloud Dashboard. This systematic structure directly addresses stakeholders’ need for formalized V&V, clear role separation, and standardized communication across IT and OT teams.

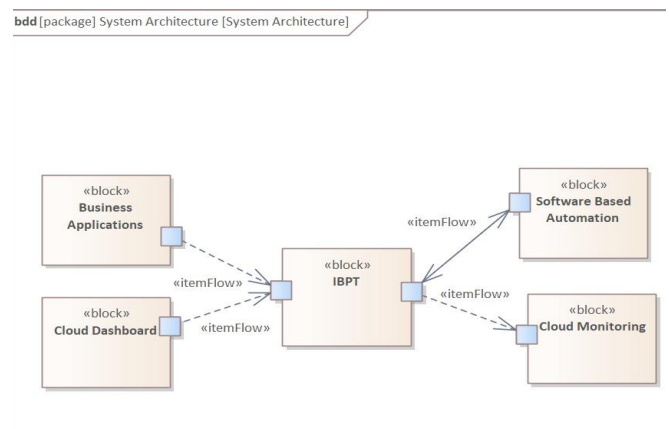


Figure 6. Detailed Communication Layer Architecture of the IBPT Solution

The Operation Usage of IBPT (Phase 3)—Verification and Validation

Previously, stakeholders have specifically pointed to V&V issues due to the independent operations on the IT side and OT side, leading to inefficiencies and communication breakdowns. With IBPT, V&V checkpoints can be unified within a single, coherent workflow that spans both IT and OT

domains. The following diagram (Figure 7) illustrates a unified approach to V&V, explicitly addressing the key challenges of fragmented and redundant V&V processes for IT-OT convergence.

It represents a structured, unified V&V process that enhances operational efficiency and traceability by embedding verification and validation directly within the modeled workflow. When an update or change is submitted, the IBPT initiates a modeled V&V sequence that evaluates the change against defined criteria. If the criteria are satisfied, the process advances toward deployment within the operational environment. If the criteria are not met, the workflow issues feedback to relevant stakeholders, ensuring that unresolved issues are addressed before any further progression.

Moreover, it provides transparency and accountability, aligning technical outcomes with strategic business goals. These detailed MBSE-based SysML diagrams clearly illustrate how the IBPT practically integrates IT and OT within the company. IBPT's role here is not just technical but also operationally strategic, directly enabling the company to achieve robust integration, streamlined operations, and rapid response to issues, consistent with stakeholder expectations and Industry 4.0 principles.

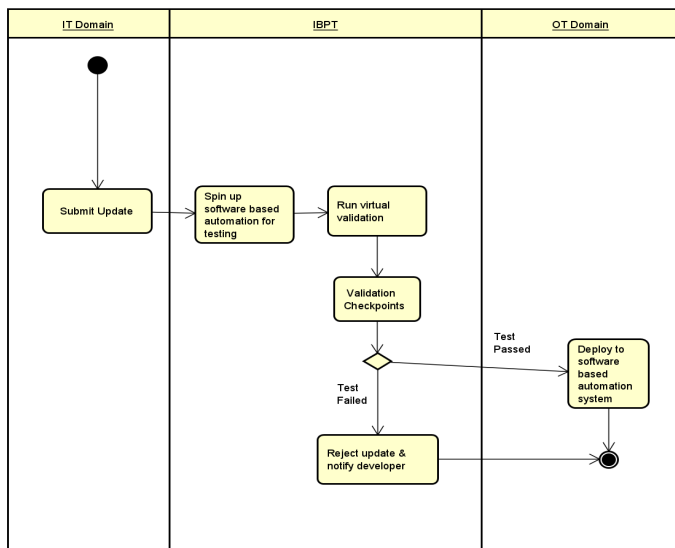


Figure 7. Unified V&V Workflow Enabled by IBPT

Solution Validation

To assess the applicability and effectiveness of the proposed IBPT solution, a validation meeting was

conducted with key stakeholders. During this session, stakeholders confirmed that the proposed set of solutions aligns with the company's operational and strategic goals. They validated that the IBPT could serve as an effective integration and coordination layer in the RAMI 4.0, which helps address the identified challenges, such as separated workflows, validation inefficiencies, and cognitive load issues. They also highlighted that the structured modeling approach in the IBPT solution helps standardize processes across various projects and supports business scalability.

Discussion and Conclusion

This case study addresses the critical challenges associated with the operational convergence of IT and OT in Industry 4.0. The proposed IBPT solution, structured and validated using MBSE within the RAMI 4.0 architecture, offers the case company a coherent, digitally integrated representation of its redesigned business processes. The IBPT's strategic positioning within the Enterprise and Workstation layers effectively employs the principle of separation of concerns, ensuring smoother and more secure interactions between IT applications and production environments. The solution is validated for meeting stakeholders' needs, including enhanced collaboration, unified verification and validation (V&V) practices, and reduced cognitive overload among IT and OT teams. Additionally, the MBSE-based development of the solution presents stakeholders with clear, traceable, and maintainable documentation of a structured approach and systems architecture of the proposed modeling of redesigned business processes.

A limitation of this study was its inability to fully implement and operationally test the IBPT solution due to constraints, including access limitations to certain tools and platforms and project time constraints. These limitations restricted the evaluation primarily to conceptual validation, scenario-driven discussions, and expert feedback, rather than practical operational deployment. In conclusion, this case study lays the groundwork for business process redesign for IT-OT convergence in Industry 4.0. We exemplify a novel digital twin approach by practically adapting the IBPT concept by Schäfer et al. (2024) in the RAMI 4.0 framework using MBSE tools. Specifically, it enhances our understanding of the applicability of the IBPT concept by tailoring it to the unique context of a platform

and validating its alignment with real-world challenges of operational efficiency and business scalability.

For continued work, we recommend a pilot test to operationalize the IBPT in a controlled, real-world scenario. It could involve integrating actual data interfaces for live sensor data, thereby fully demonstrating end-to-end functionality from client onboarding through the IBPT to software-based automation execution. Such practical testing would allow rigorous verification of the IBPT's embedded logic and provide detailed insights to further refine and update the model.

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