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Industry 4.0 Digital Transformation: Information Technology (IT) – Operations Technology(OT) Convergence Model and its Implementation in Asset-Heavy Manufacturing Industry

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Abstract

Industry 4.0 is the novelapproach of the fourth industrial revolution for managing the manufacturing enterprise. Industry 4.0 heavily focuses on automation and interconnectivity of machines and the collection of real-time data and data analytics for digital transformation of the enterprise. Within an industrial enterprise, the network and data analytics falls under the purview of the Informational Technology (IT) department, and the machines and their data are managed by operations called Operation Technology (OT). The need for synergistic functioning of the enterprise under the new paradigm of industry 4.0 has brought the convergence of these business verticals. However, IT and OT are two vastly different business verticals, and their convergence has its merit and challenges. This paper tries to look at these challenges from an organizational perspective, and it proposes an integration and implementation model in an asset-heavy manufacturing industry.

Keywords: Industry 4.0, Digital Transformation, IT-OT convergence, Smart 4.0, Technology integration.

1. Introduction

The transition of industry represented in Figure 1 depicts the evolution of manufacturing sector from manual labor centric mechanizationto cyber-physical IoT based smart automation, also known as Industry 4.0 (T. Daim et al., 2019).Real-time data collection, processing, and communication, along with process automation, forms the crux of the Industry 4.0. In this phase of the industrial revolution,an organization can survive and thrive only through digital transformation.Real-time decision-making is made possible because of pervasive network connectivity and comprehensive data processing power that results in a proactive and agile system with improved productivity (J. Abonyi et al., 2020). However, a structured introduction process is required for a cost-effective and successful implementation of Industry 4.0. This structured implementation process focus should be based on the specifics of each case. A thorough analysis and evaluation of all available Industry 4.0 methods is required to select the most suitable ones for an individual case or company (C. Liebrecht, 2021).
Each organization has its own culture and processes. Therefore, the implementation of Industry 4.0 is not just about machines but a transformation of the organizational culture, business verticals, and processes. Two such verticals that are prominently coming together during implementation of Industry 4.0 initiatives,are Informational Technology (IT) and Operation Technology (OT).

Most enterprises havebuilt, operated, andmaintained OT and IT infrastructure as two separate departments or technologies. Even though they are under the same organizational umbrella, they work under independent Key Performance Indicators (KPIs). Their reporting structure, problem escalation methods, and hierarchies are so different that they do not seem contemporaneous. Such disparities have resulted in the formation of silos of two technologies within the same organization. Such silos are detrimental to the free flow of real-time data and knowledge. (K. Sharma, 2017).

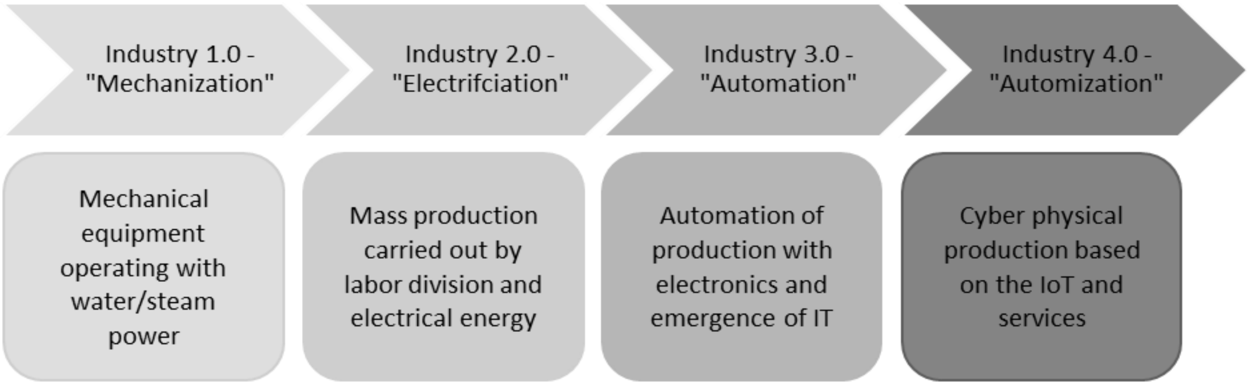

Figure 1: Industrial Revolution Timeline (T. Daim et al., 2019)

Since Industry 3.0, these two technology pillars of an organization have started the process of convergence. For the last couple of decades, IT infrastructure has been connected to OT systems via Industrial Control Systems (ICS) based on Programmable Logic Controller (PLC) technology. The advent of Industry 4.0 is driving more intelligence, automation, and optimization in these systems. The business landscape has been revamped because of the integration of IT and OT systems. As the modularization of the technology is gaining pace and more of these two technology pillars are being based on off-the-shelf components, managing the convergence and the associated risk to the whole value chain is now critical to businesses seeking to gain competitive advantage. This paper looks at the current landscape of Industry 4.0 from the same perspective and dwells on the practical aspects of successfully implementing IT-OT convergence.

2. Literature Review

2.1 Enablers for Industry 4.0

The research reviewed for this paper on enablers for industry 4.0 was focused on two perspectives: the technology enablers and the business enablers. (Y. Chen, 2017) looked at the industry 4.0 technological enablers from integrated and intelligent manufacturing paradigms (i2m). The study identified ten critical elements of technologies that majorly contributed to the evolution of the i2m paradigm. These technologies include six supporting elements: three-dimensional (3D) printing or additive manufacturing, robotic automation, advanced materials, virtual or augmented reality, the Industrial Internet, and Cyber-Physical Systems (CPSs), and four foundational elements: big data analytics, cloud computing, applications, and mobile devices. (T. Daim et al., 2019) looked at the enabling technologies as the prime driver more from an economic perspective as they attracted more investments in Industry 4.0 initiatives. As per the study, big data, predictive maintenance, cloud computing, digital twin, autonomous robots, augmented reality, advanced sensors, and 3D printing form the basis of the economic development in industry 4.0
(S. Rajput and S.Singh, 2019) looked at business enablers for industry 4.0 from a Circular Economy (CE) perspective. The study used DEMATEL methodology to recognize the cause and effect of these enablers on CE and manufacturing performance. These enablers included Value Networks, Integration, Maintenance and Recovery, Flexibility, Visual Computing, Scalability, Modularity, Reliability, Internet of Things (IoT), Self-Configuration, Self-organization, Blockchain, Infrastructural Building, Service Economy, System Integration, Energy and Waste Recovery, Quality of Services, Big Data and Collaborative Robotics. (S. Luthra et al., 2020) used the Interpretive Structural Modeling (ISM)-fuzzy MICMAC approach to assess the interrelationship among key enablers. The study included external factors such as understanding the benefits of Industry 4.0 (I4) practices, research & development on itsimplementation, and helpful government policies.It also considered the effects of internal business factors such as change management, digital technologies,the likeliness of innovative business model adoption by the complete network, and intra-organizationsand inter-organizations trust-building measures. The study concluded that the supportive government policiesfactor was the most effective enabler in the widespread adoption of Industry 4.0.

2.2 Industry Surveys and Literature Reviews

Several research studies which surveyed the current market sentiment in the adoption and implementation of Industry 4.0 were reviewed. (R. Hamzeh et al., 2018) conducted a study to capture the manufacturers' opinions in New Zealand regarding issues in implementing Industry 4.0 initiatives. The topics listed in the survey were the level of awareness about Industry 4.0, relevancy to the company, preference of department in implementation, potential benefits to the business, the timeline for future Industry 4.0 initiatives, and significant challenges and obstacles. They found accounting and finance as the first preference while manufacturing cost saving was the highest benefit listed by manufacturers to implement Industry 4.0 initiatives. A similar survey was conducted by (F. Yu and T. Schweisfurth, 2020) in the Danish-German border region Small and Medium Enterprises (SME). The surprisingly found low enthusiasm among the SMEs, which the study attributed to low awareness and knowledge of existing technologies, while SMEs with more automation in their factories tend to be more aggressive about Industry 4.0 initiatives.

(C. Enyoghasi and F. Badurdeen, 2021) did an extensive survey of research work around the sustainability of industry 4.0 technologies, focusing on the 6R model (Reduce, Reuse, Recycle, Redesign, Recover, Remanufacturer). The study used clusters of metrics for evaluating products, processes, and system sustainability affected by Industry 4.0 technologies. The study concluded that in the context of industry 4.0,multiple metrics clusters, which directly affect the sustainability of the system as well as the product and processes, have been ignored and need further research. (C. Cagnettia et al., 2021) did a systematic literature review studying the relationship between lean manufacturing and industry 4.0. The subsequent analysis shows that the relationship between the two technologies is well documented for strategic implications compared to technical or tactical points of view. (D. Pivoto et al., 2021) carried out a literature review study for the research work in types of architecture and frameworks for Cyber-Physical Systems (CPS) in Industry 4.0. They inferred that the CPS projects focused mainly on Industrial Internet of Things (IIoT) and connectivity technologies and emphasized vertical integration.

2.3 Data Analysis and Modeling

(I. Pawłyszyn et al., 2020) studied the problem of unawareness of the solutions available for implementation of Industry 4.0. The study tried to model the diffusion of knowledge locally among enterprises which are in Marshallian clusters. They concluded that in a Marshallian cluster, the initiative lies with the larges enterprises to innovate and evaluate new solutions and disseminate the knowledge for the betterment of the ecosystem. (I. Ehie et al., 2020) tried to empirically model the influence of IT-OT Convergence on the adoption of IoT in manufacturing organizations. The motivation behind the research is the understanding of the authors that considerable researchhas been done on thedetermining factorsof IoT adoption but to provide a roadmap for IoT adoption in the manufacturing industry, more investigation is needed. The study concluded that the key IoT enablers are IT infrastructure, IT governance, and interoperability, while staff collaboration is a factor thathas a mentionable but lowerimpact on IT-OT convergence.

2.4 Barriers and Challenges to Industry 4.0

(C. Chauhan et al., 2020) performed an empirical investigation of intrinsic and extrinsic barriers to Industry 4.0 in emerging economies. Forty-nine factors were considered, and their effects were studied on operational efficiency and supply chain competence. The findings of the study suggested that the intrinsic and extrinsic barriers are negatively linked with digitalization. The analysis also reveals that operational performance and supply chain competency improve with the adoption of Industry 4.0. (M. Cugno et al., 2021) studied the relationship between organizations' openness to accepting industry 4.0 and their performance and the impact of barriers and incentives on this relationship. The result showed a positive relationship between openness, performance, and perception of barriers and incentives.

(A. Mujumdar et al., 2021) focused on the Indian textile and clothing industry's management of the Industry 4.0 barriers. The study proposed a triple helix frame to include the three players viz the textile and clothing industry, the academia, and the government as a model of innovation. The researchers used Interpretive Structural Modeling (ISM), Analytic Hierarchy Process (AHP), and Decision-Making Trial and Evaluation Laboratory (DEMATEL) to model the enablers and barriers of Industry 4.0. The study concluded that scarcity of qualified professional, unsupportive government policies,absence of commitment or thorough understanding of Industry 4.0 concepts and its benefits among top management,andinsufficient research and development initiatives in Industry 4.0 as the leading factor for creating barriers in the adoption of Industry 4.0 in the textile and clothing industry in India.

2.5 Implementation of IT-OT Convergence

(V. Ramírez-Durán et al., 2021) Proposes a novel approach facilitating the implementation of Industry 4.0 by focusing on the customer life cycle. The main contribution of the research work is to provide a methodology that can help software engineers create new software services aligned with Industry 4.0. The methodology includes the following six stages: definition of objectives and goals, the building of semantic descriptions, building the 3D visualization, architecture design, implementation of customer services, deployment in production.

3. Challenges in IT-OT Convergence

OT technologies that mainly consist of Industrial Control Systems (ICS), manage the physical world of manufacturing while the IT systems manage data and communication. IT technologies evolved in the day and age of internet connectivity, which has made it more open, and with the advent of hyper-globalization, standardization was vital for its proliferation. In contrast, OT technologies belong to an earlier era that saw more provincial growth stories. Hence, these technologies were designed for specific regional purposes and are proprietary, making them seem closed.

3.1 Organizational Challenges

Personnel: There is a significant communication gap between OT and IT personnel because of differences in their knowledge domains. For example, OT departments comprise process specialists with sound domain knowledge of the process and its business effects, whilethe IT departments are heavily dependent on computers engineers specializing in networks or other technical specialists,not completely conversant with OT technologies.(K. Sharma, 2017).

Development and Accountability: The IT and OT professionals' profiles are affected by the inherent organizational separation.Personnel in the OT department are more production-oriented process specialists. The business units they report into also differ in many aspects across a single organization. For example, based on the position in the value chain of an enterprise, each OT department has different Key Performance Indicators (KPIs). This non-harmonized nature is pervasive across OT departments. On the contrary, A centralized management approach is applied to IT platforms and processes in all the business units. An ITdepartmentownsan organization's software and computer hardware assets and mainly consists of network specialists and programmers(K. Sharma, 2017).

Administrative:As mentioned earlier, IT is managed by a centralized organization that has more coordinated strategies and unified organization-wide standards and protocols for infrastructure and software. OT strategies are not standard across the enterprise. They vary depending on the location of the physical assets (manufacturing plants and factories) and are based on regional laws and constraints on the supply chain(K. Sharma, 2017).

3.2 Infrastructural Challenges

The majority of businesses treat IT and OT as distinct technologies with separateobjectives. IT usually falls under the purview of the Chief Information Officer (CIO) and support general business applications, such as customer relationship management (CRM), Business Process Management (BPM), Project Management (PM), Business Intelligence (BI) solutions, or Enterprise Resource Planning (ERP), While OT fall under the Chief Operations Officer (COO) or general manager and support production-related applications, such as Manufacturing Execution Systems (MES), Order Management System (OMS), Inventory Management System (IMS), or Supervisory Control and Data Acquisition (SCADA) systems.

Technological: OT systems call for a real-time operating system (OS) and localized hardware (Edge Computing), whereas IT systems for a time-sharing OS which is network-based (Cloud Computing)(K. Sharma, 2017). Also, OT cannot adapt to the fast-changing landscape of technology. Hence, both cannot be served with a single OS and hardware architecture. These limitations are unsurmountable for a brownfield installation where the capital cost and interruption in production and supply chain are prohibitive. An OT-specific standard for networking, communication, and security turns out to be necessary, which becomes OT vendorsimposedabsolute standards.

Generational Upgrades: A typical technology upgradation cycle for the IT department is two to three years for personnel hardware and usually on demand for enterprise-wide software. However, OT cannot handle such a short cycle for upgradation. An upgradation follows a strict protocol of testing and thorough validation at the customers' end. The upgradation cost is also significantly high with critical business operations involved. The usual cycle for upgrading machines and technology on the OT side is over twenty tears. (K. Sharma, 2017).

3.3 Security concerns

Dealing with security attacks is the primary concern in the day and age of the internet today. Unlike the considerable amount of firewall protection and monitoring imposed on IT systems, OT systems are relatively open. With the push for network integration of OT for remote accessibility, OT systems are more vulnerable to security attacks. These attacks can cause monetary harm and safety and security concerns for personnel on the shop floor, as the accessibility to sensors, actuators, and other machinery is compromised. Failures in a manufacturing environment due to various reasons are common occurrences, worsening the problem as these failures can be exploited by the attackers. A sustainable and economically viable production system in the IoT era should have the ability to autonomously function and recover from security attacks (J A Stankovic, 2014).

4. IT-OT Convergence Conceptual Model

Several attempts have been made to model Industry 4.0 implementations. Nearly all of them start with setting the organization's baseline by assessing the maturity of the existing setup before the implementation of IoT technologies. The German National Academy of Science and Engineering created Acatech Industrie 4.0 Maturity Index (G. Schuh et al., 2020) that is used prominently on the business side. On the academic side, there are industry-specific models such as the Machine Tool (MT) maturity model (L.D. Rafael et al., 2020), other models for Small and Medium-sized Enterprises (SME) by (S.Mittal et al., 2018), for Industry 4.0 readiness assessment created by (A. Schumacher et al., 2016), and Maturity Model for Digitalization by (C. Klötzer et al., 2017).

One of the most referenced models for industry 4.0 is proposed by (A. Frank et al., 2019). The modified version of that model for IT-OT convergence is depicted in Figure 2.This model was selected becauseit is divided into the base and front-end technologies of Industry 4.0.The front-end technologies are synonymous with the IT vertical, and Industry 3.0 represents the OT vertical,which forms the base-end technologies. Thus, an IT-OT convergence forms the basis for Industry 4.0. Furthermore, the model proposed by (A. Frank et al., 2019) provides animplementable guideline in terms of technologies and practices, which is particularly important for the narrative of this paper as it looks at the practical aspect of implementing IT-OT convergence initiatives inthe asset-heavy manufacturing industry.

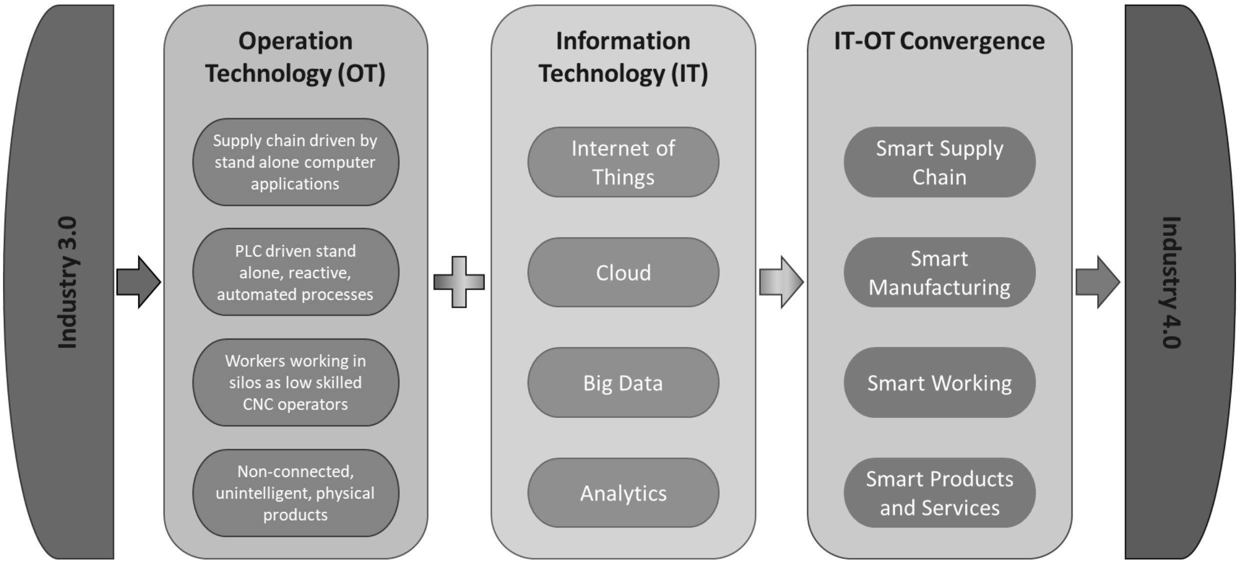

Figure 2: Conceptual IT-OT Convergence Model - Smart 4.0 (A. Frank et al., 2019)

4.1 Smart Supply Chain

The Smart Supply Chain (SSC) isthe first dimension that is looked at in the IT-OT convergence model (Figure 2). SSC has been referred to as Supply Chain 4.0 (G. Frederico et al., 2020) and Logistics 4.0 (J. Strandhagen et al., 2017). SSC deals with the value chain outside the factory. It uses technologies for horizontal integration of the business with external suppliers and mainly affects the cost and lead time (A. Frank et al., 2019). SSC has tremendous opportunities due to the technology enablers such as network connectivity with higher bandwidth, big data, and real-time data sharing (G. Frederico et al., 2020). Smart Supply Chain includes smart material handling at different touchpoints such as the docks, assembly line, and warehouse storage. The increased use of mobilerobots and guided vehicles can facilitate smart material handling (A. Frank et al., 2019). Industry 4.0 introduced technological changes that have tremendously helped supply chain mapping, which can yield two-fold advantages of improving visualization and monitoring of the processes across the value chain and increasing the supply chain's resilience (M. Mubarik et al., 2021).

4.2Smart Manufacturing

Smart Manufacturing (SM) has beenan integral part of the Industry 4.0 concept since its introduction (H. Kagermann et al., 2013). It forms the core of Industry 4.0 (B. Meindl et al., 2021). However, there is no generally accepted definition of smart manufacturing (A. Kusiak, 2018). According to the National Institute of Standards and Technology (NIST), smart manufacturing is a manufacturing system that is entirely integrated, collaborative, and nimble to respond in real-time to changes in signal on supply and demand side, workforce, and equipment availability. A more comprehensive and formal definition is given by (A.Kusiak, 2018). Smart Manufacturing integrates multi-generationalmanufacturing assets. This integration is achieved via sensors and communication technologies, interfacing with computing platformsthatperformdata-rich modelingand simulation, and provides better control and predictive capabilities.

Industry 3.0 started the automation process of the industrial environment, particularly the manufacturing sector, with the use of Industrial Control Systems (ICS) based on Programmable Logic Controller (PLC) technology (H. Kagermann et al., 2013). The related technologies such as the sensors, memory, communication networks, and processing units started becoming modular and cheaper, further abetting the advancements in connected and embedded systems. These systems aimed to control the different components of the factory floor like conveyors, machines, and tools, providing a feedback loop of data. This data was used to simulate the manufacturing systems virtually giving rise to Smart Factories and Smart Manufacturing of Industry 4.0 (L. Dalenogare et al., 2018). The technological trend for Smart manufacturing is now moving towards Augmented Reality, Additive Manufacturing, and Predictive Maintenance which is further digitally transforming the manufacturing industry (J. Zenisek et al., 2021).

Smart Manufacturing benefits an organization by vertically integrating its information systems and provides virtualization, which helps process planning, simulation, and predictive maintenance. Automation of individual machines and machine-to-machine communication improves productivity and improves quality while providing traceability throughout the process, starting from raw materials to in-process quality checks and compliance procedures, finally tagging this information to finish products. (A. Frank et al., 2019). Smart manufacturing also helps mitigate the negative environmental impact from manufacturing activity, which constitutes twenty percent of global CO_2 emissions according to the United Nations Environment Program (UNEP)(S. Ramakrishna et al., 2017).

As the Smart Manufacturing model evolves, it is moving towards a service-oriented model for the whole industry. The servitization model is still in its infancy and lacks any structured paradigm or reference architecture. The approach for the time being should be an incremental transition where small segments of the value chain move towards As-A-Service (AAS) platforms (M. Moghaddam et al., 2018).

4.3 Smart Working

This dimension of industry 4.0 is also called Smart Work or Operator 4.0, defined "as a smart and skilled operator who performs not only cooperative work with robots but also 'work aided' by machines if and as needed." (D. Romero et al., 2016). The production personnel of Industry 3.0 are operating and interfacing with CNC machines with low-skilled jobs of loading and unloading parts and fixing minor issues with machines (D. Zakoldaev et al., 2019). Industry 4.0 factories require competent and skilled operators who develop their creative and innovative skills without compromising their efficiency at the job (E. Kaasinen et al., 2019). Recently the human role in Industry 4.0 and all the associated ethical issues have been considerably deliberated. The fourth industrial revolution is completely changing the identity of the operators along with what and how they do their jobs (L. Gazzaneo et al., 2020). However, the is a general acknowledgment that workers/ operatorsmust be enhanced rather than be replaced and that they are strategically important for the smooth functioning of any manufacturing endeavor (E. Kaasinen et al., 2019).

The key technologies which enable these enhancements of the operators need to improve their cognitive, sensory, physical, and interaction capabilities (L. Gazzaneo et al., 2020). Virtual reality is one of the technologies that enrich the cognitive abilities of the operator as the capability to interact with intangible assets, and digital content is highly interactive and efficient (F. Longo et al., 2017). Artificial intelligence allows for quick real-time decision-making and planning and predictive maintenance (Y. Cohen et al., 2019). Augmented reality improves the interaction capabilities of the operator as it connects the virtual to the real with a variety of value-added content, an operator can perceive and react to the environment in an efficient manner (F. Longo et al., 2017). A pneumatically or hydraulic powered exoskeleton is a biomechanical system that multiplies the operator's physical strength and reduces the effort in manual processes (D. Romero et al., 2016). Cobots are collaborative robots thatshare the same working space with humans and act as temporary workers or permanent helpers for operators (Y. Cohen et al., 2020).

The technologies discussed above haveconsiderably changed how workers approach their work in Industry 4.0 context and their required skills and capabilities (A. Szalavetz, 2019).These technologies gather a considerable amount of data which is processed in real-time. As a result, Operator 4.0 is expected to be more intelligent, learn new skills, and perform complex tasks. These expectations cause a significant cognitive load, affecting the operator's performance if there are no supporting systems and technologies. Computer Vision (CV) is one such solution that can reduce the operator's fatigue. CV solutions help in object detection, recognition, motion capture, and analysis (Y. Cohen et al., 2019). Digital work instruction combined with augmented reality can also help operators reduce cognitive burden by guiding them through their workflow and reducing errors (A. Carvalho et al., 2020).

4.4 Smart Products and Services

The design and development of smart products require a very well-defined product development process. In addition, there are many new disruptive and innovative technologies introduced due to Industry 4.0 revolution that represents a considerable potential for industrial design and prototyping, which further helps smart product development (M. Nunes et al., 2017). The front-end technology for smart products comprises digital components such as connectivity, monitoring, control, optimization, and autonomy. Embedded sensors provide wireless connectivity and monitoring capabilities where the user can know the status of the product. Self-learning software with AI capabilities provides the autonomous operation of the product. Cloud connectivity provides the control, and with built-in analytical abilities, the product operations can be optimized (A. Frank et al., 2019).

A recent study by (A. Frank et al., 2019a) termed servitization and Industry 4.0 as two of the fast-growing business models accelerating manufacturing-based enterprises' digital transformation journey. Most business models are only focused on creating value for the customer. The combination of Industry 4.0 and servitization form a push-pull model of technology and demand that generates value for the customer and the enterprise by improving production planning, control and reducing time to the market (A.

Frank et al., 2019a). IoT aided servitization model helps enterprises extend their value chain to help theircustomer's customers and improve its profitability (A. Rymaszewska et al., 2017). The innovativeness of the servitization business model is that it sells the use of the product than the product itself (K. Wang et al., 2019). An increasing trend of outsourcing manufacturing-related services to a third party and industry 4.0 has accelerated this trend (J. Huxtable et al., 2016). Convergence of IT and OT, which is the crux of Industry 4.0, drive towards servitization of everything in manufacturing enterprise as depicted in Figure 3.

5.0 Implementing Convergence of IT-OT

Figure 3 shows the stages of the industry 4.0 model (Figure 2) as IT-OT converges.IT-OT convergence is a multistage process that goes beyond the integration of IT and OT departments. The effect of this change is felt throughout the value chain, especially by the third-party vendors and contractors who play a significant role in this integration journey.As an organization matures through the process and moves towards servitization, it focuses on product and customer management. This realignment leads to greater integration of internal and external functions in asset-heavy manufacturing industries, giving rise to new business models.
The challenges for IT-OT convergence are related to subtle aspects of business management. Overcoming the culture and governance issues are the most complex problems to solve than the technical aspects of the integration process (R. Hayes, 2020). According to the study done by (J. Müller, 2019), the top three barriers to the successful implementation of any Industry 4.0 initiatives are acceptance and participation from the employees, lack of new ideas from management, and lack of communication

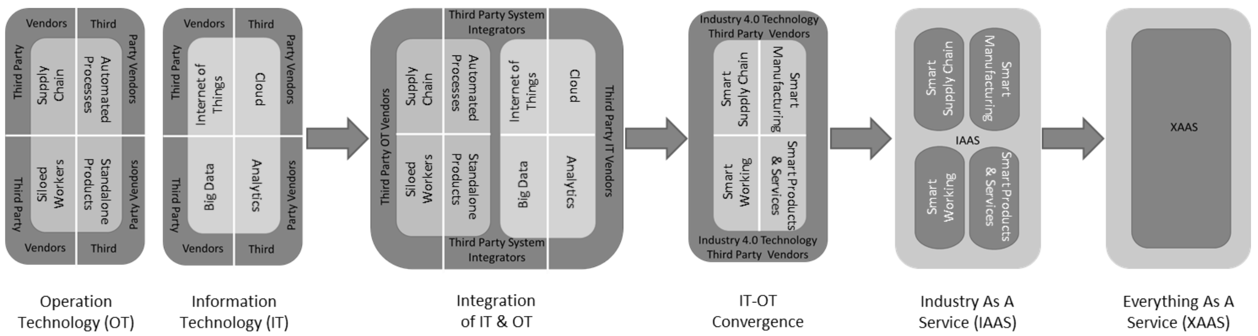

Figure 3: Stages in IT-OT Convergence (R. Hayes, 2020)

between departments. The secret to a successful and sustainable IT-OT convergence is rigorous communication, alignment between departments, and continuous course corrections. For any asset-heavy organization, the implementation strategy for its IT-OT convergence should be multi-phase depending on the organization's maturity level. Following are the five phases of implementation of IT-OT convergence (K. Steenstrup, 2020).

Phase 1: Create Baseline and Awareness

At this stage, the organization's technological architecture resembles an Industry 3.0 setup that is not organized and works in silos with sporadic connectivity. The end-to-end integration of IT and OT is still a vision, and few projects are being run in pockets throughout the organization. The enterprise is still trying to understand the technology paradigm that fits its needs and, in that context, is interacting with several vendors to narrow down the vendor list based on vendor capabilities and their fit into the organization's digital framework. At the same time, the organization is looking internally and comparing itself with contemporaries to set a baseline and assess the systems and platforms that need changes. This step also involves the selection of internal teams to spearhead the integration process. This process should be transparent and with targeted positive messaging for all the stakeholders to consume and get onboard. It must acknowledge that the OT vendors and systems that are inflexible, intransigent, and insulated exclusive systems are being transformed to commercially available connected systems with their own risk and work cultures.
Benefits of this stage include creating a baseline and awareness of the variety of OT system technologies that the organization has been using and the extent to which OT has converged in the enterprise and the inventory of OT systems and their software asset management (SAM) tools.

Phase 2:Trust Building and Buy-in

It is the OT management that will require considerable change during this phase. Change is vital in business for remaining relevant and competitive but is often feared and resisted. To arrive at a consensus, the operations department must agree on why they seek realignment and convergence. The reasons for the change need to be documented and communicated, explaining the cost and adverse effect of not changing. As the new systems are being implemented, the question of ownership of these systems will rise. It will require a considerable collaboration effort between departments to draw the fine line of system ownership. A new deployment and management process needs to be formulated. Older OT systems either need to be assimilated or substituted. This reorganization of OT systems must be managed with deft hands and by leadership that is culturally sensitive and discreet. Applying the principles of change management will be paramount. However, this change will have its benefits of improved performance, visibility, and security.

Benefits include securing senior management buy-in to proceed with changes in technology governance and identifying and communicating goals and objectives.

Phase 3: Creating a New Template ofProcess andGovernance Model.
After building consensus, the next step is to decide the Key Performance Indicators (KPI) for the organization to follow. Cost management will be crucial as OT systems require significant capital, IT support systems, and security, maintenance, and management personnel. OT systems will also need software governance, a life cycle plan, and a plan for software life cycle management, data management, and cybersecurity strategy. These plans must be standardized and made a part of OT leadership's business management process. Finally, a unified incident management approach needs to be decided, and people with the right skills set need to be designated to support specific OT systems that may have support needs.
Security risk mitigation through planning and establishing governance hierarchy is one of the significant benefits of this phase, along with the consolidation of project timelines and minimization of investment in licensing through an optimized IT-OT software management plan.

Phase 4: IT-OT Convergence
Each organization has a culture ingrained in its psyche and is reflected in its procedures, operations, and decision-making. A standardized workflow and aligned KPIs ensure effective management of an organization. With the convergence of IT and OT, the data flow happens across the enterprise seamlessly. This visibility to data is a significant milestone of this phase. All systems are designed to support this flow across the organization. For the first time, the organization has a clear line of sight to the OT operations because of uninterrupted, real-time, and accurate OT data access. This access provides excellent situational awareness throughout the value chain. Metrics like performance and efficiency now have the true meaning as it reflects the status of machines and goods accurately. The decision-making becomes real-time with an added benefit of predictiveness due to data historians, especially for asset-heavy businesses.

Phase 5: Standardization and Optimization
In this stage, after the IT-OT converges, the stakeholders, the feedback, the investment, the decision-making, and the resources are all connected throughout the organization. Feedback from stakeholders is also used to adjust and improve processes. Modern OT systems have separable layers or servers, OSs, and applications. For that reason, an organization may consolidate support for these systems by better integrating with third-party vendors. Benefits of this phase include improved and standardized processes resulting in reduced staff for supporting OT systems to free up resources for higher-value activities, standardized OT sourcing, and mitigation of the effects of talent shortages in support areas.

6.0 Discussion

It is a well-accepted fact by most researchers that by converging OT and IT technologies, systems and practicesinto a unified architectural system, organizations can gain in efficiencyvia improvedinteroperability and automation, which further stimulates innovation and growth. However, most of the prior research done in Industry 4.0 and IT-OT convergence focuses on the security aspect of the integration, barriers to implementation, and modeling of the effect of the change through surveys. In this paper, we have focused on the more practical aspect of implementing this organization-wide change. Different organizations are at different maturity levels regarding their operations and workforce management and their proclivity to the adoption of new technology. This paper will guide organizations in any stage of industry 4.0 technology convergence to understand the challenges they might face in their journey to sustainably implementing their industry 4.0 initiatives. The organization can then refer to the Smart 4.0 model to understand the value chain effects and follow the five-phase maturity-based implementation guide.

7.0 Research Gaps

The industry 4.0 technology convergence process will completely revamp the structure and functioning of any organization. It is once in a century revolution that will alter the well-established value chains of various manufacturing industries. This profound effect needs to be studied for end-to-end effect on each specific value chain. There is a dearth of research on how this change will affect the product development cycles and the consequent effect on tier 2 and tier 3 suppliers. As mentioned in this paper, the servitization model is gaining traction, significantly enhancing the customer value proposition in B2B business. However, the effect of the same on product development in the B2C segment needs more exploration. As proposed in this paper, the final stage of the technology integration, which leads to new business models like Everything As A Service (XAAS), is also relevant for research in terms of value chain effects and changing dynamics on world economies.

8.0 Acknowledgements

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9. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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