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Challenges in The Design of Complex Systems in 2040

Essay Title:

Designing Human-Centered Enterprises for 2040 as an Evolving Cyber-Physical-Social System

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ABSTRACT

In this essay, I explore the future of global high-tech manufacturing through the lens of a consultant advising an enterprise in the year 2040. I begin by defining key characteristics of high-tech global design and manufacturing enterprise and then analyze major challenges such as demographic shifts, climate change, geopolitical instability, and technological convergence. Building on this foundation, I identify workforce adaptability as a critical challenge and propose a forward-looking solution framework grounded in Industry 5.0 and Evolving Cyber-Physical-Social Systems (E-CPSS). In the proposed framework I emphasize decentralized micro-enterprises, layered cybersecurity, sustainability integration, adaptive decision-making, and human-AI collaboration. I conclude by outlining key areas for future research to support the design of resilient, inclusive, and intelligent enterprises in 2040 and beyond.

1. Introduction

As a consultant advising a high-tech, global manufacturing enterprise aiming for leadership in 2040, it is evident that the future landscape will be dramatically different from today. Based on the defined scenario—*"You are a consultant working for a high-tech, global manufacturing enterprise." That company wants to position itself to be a high-tech global design and manufacturing enterprise in the year 2040. As a consultant, you want the company to succeed both domestically and globally"*, I begin by clarifying the key terminology in the story to define the scope of this paper: high-tech enterprise, global design and manufacturing enterprise, and succeed both domestically and globally. Next, I will outline the requirements for such enterprises, identify the challenges tied to these requirements, and finally propose a framework to manage those challenges effectively.

1.1. Foundational definitions

High-Tech Enterprise

A high-tech enterprise is a company that operates at the forefront of technological innovation, integrating advanced digital technologies into its business and production processes. In the context of manufacturing, these enterprises embrace end-to-end digital transformation as a strategic imperative [1]. They leverage Industry 5.0 technologies, characterized by pervasive connectivity, data analytics, automation and robotics, and other cutting-edge manufacturing systems [2], to fundamentally enhance productivity and flexibility. In sum, a high-tech enterprise is defined by its use of state-of-the-art technology and continual innovation to transform products, processes, and business models in the modern industrial landscape [1]. The core concept is related to Industry 5.0 which I will address with details in Section 4 of this document.

Global Design and Manufacturing Enterprise

A global design and manufacturing enterprise is a company whose innovation, production, and supply chain activities are distributed across multiple countries, forming an integrated international network. Such an enterprise develops products through globally dispersed design and engineering teams and manufactures them via international production networks, often referred to as global value chains (GVCs) [3]. In these networks, goods are produced and assembled in different regions of the world, taking advantage of each location's specializations and efficiencies. Critically, it aligns product design closely with its worldwide manufacturing capabilities and business strategy, so that new products are developed with global markets in mind and can be produced and delivered efficiently across diverse regions. This

comprehensive global footprint means the enterprise manages complex international supply chains, distributed innovation processes, and multiple production sites, all orchestrated to serve both local and worldwide markets effectively [3]. In essence, it is a truly international industrial firm with the capacity to design anywhere, build anywhere, and sell everywhere, by virtue of its integrated global operations.

Succeed Both Domestically and Globally

To succeed both domestically and globally means that an enterprise achieves sustained competitive performance in its home market while also thriving in international markets. In strategic terms, this denotes a high level of competitiveness – the European Commission, for example, defines competitiveness as the ability of companies to effectively compete in both domestic and global markets. A company that succeeds on both fronts excels against local rivals at home and can also win market share abroad against international competitors.

So, the firm must continually innovate and maintain quality and cost advantages to stay competitive in diverse markets, leveraging strengths that travel across borders (e.g. strong brands, superior technology, or efficient production) [4]. Second, it needs robust operational resilience – the capability of its operations and supply chains to absorb shocks and recover quickly from disruptions (such as economic downturns, supply chain crises, or geopolitical events) [5]. Third, succeeding globally demands agility in regulatory adaptation: the enterprise must navigate and comply with different countries' laws, standards, and cultural expectations, adapting its products and processes to meet local regulations while still benefiting from global scale. Using the defined terminology, I want to synthesize the asked story as our role as consultants involves guiding a high-tech enterprise—a firm driven by digital transformation and advanced manufacturing technologies—toward becoming a global design and manufacturing leader by 2040. This vision requires not only operating through globally distributed innovation and production networks but also achieving competitiveness, resilience, and regulatory adaptability across both domestic and international markets. With these foundational definitions established, I now turn our attention to speculating and gathering key contextual information about the year 2040, including projected population trends, global warming and environmental challenges, food demand, emerging technologies, the transformative role of AI, and shifting social structures. This exploration will inform Section 2, where I define the characteristics of a successful high-tech enterprise in 2040.

1.2. Key contextual information about the year 2040

In addition to foundational definitions, to define the characteristics of a successful high-tech enterprise in 2040, we must first understand the broader context in which it will operate. In this section I outline key global trends and challenges—ranging from demographic shifts to technological, environmental, and geopolitical dynamics—that are expected to shape the industrial and socio-economic condition by 2040 through exploring several relative data sources and articles and also use my speculation about the future by reflecting on the current trends.

Population, Food Demand and Challenges

According to the latest data observed from the United Nations, the global population reached approximately 8.09 billion in 2024 [6]. Projections estimate this figure will rise to 9.18 billion by 2040, marking an increase of over 1 billion people in less than two decades [7]. This demographic surge will place unprecedented pressure on global food systems, especially in regions already facing agricultural vulnerabilities due to climate change, land degradation, and water scarcity. The Food and Agriculture

Organization estimates that food production will need to increase by at least 50% by 2040 to meet global demand [8], with some regions such as Sub-Saharan Africa requiring more than 100% growth to feed their expanding populations. However, current growth trends in agricultural yield fall short of these targets, raising serious concerns about food security. Combined with urbanization, shifting dietary preferences, and climate-induced disruptions to supply chains, this creates a multifaceted challenge—one that future high-tech enterprises must consider, both in terms of sustainable operations and strategic innovation in agri-tech, supply resilience, and circular resource use.

Geopolitical Landscape

The term geopolitics denotes a broad analytical framework in international relations, encompassing different phenomena such as political instability, tensions and military conflicts between countries, terrorist threats or geographical events that can have regional or global impacts [9]. In the context of global manufacturing, geopolitical dynamics profoundly influence economic performance through disrupted supply chains, trade restrictions, resource access limitations, and shifting alliances. As nations increasingly prioritize strategic autonomy and economic security, companies must navigate rising protectionism, localization trends, and complex regulatory environments. Moreover, competition over critical technologies—such as semiconductors, AI, and clean energy systems—has turned technological dominance into a geopolitical objective. By 2040, successful high-tech enterprises will need to build geopolitical resilience, diversifying operations and suppliers while maintaining agility in responding to fast-changing global power dynamics.

Labor Market and Workforce Evolution

The labor market is undergoing a profound transformation driven by demographic shifts, technological advancement, and changing work expectations. By 2040, the global workforce will reflect a mix of aging populations in developed countries and youthful labor surges in parts of Asia, Africa, and Latin America, creating asymmetries in labor availability and skills. Simultaneously, automation and artificial intelligence will reshape job structures, displacing routine tasks while increasing demand for digital, cognitive, and cross-disciplinary capabilities [10]. The rise of hybrid and remote work models, gig-based labor, and AI-augmented roles will challenge traditional workforce planning and require enterprises to adopt flexible talent strategies. To remain competitive, high-tech enterprises must invest in continuous reskilling, human-AI collaboration frameworks, and inclusive labor policies that harness diverse human capital while navigating cultural and generational expectations across global operations.

Global warming and Energy Transition and Sustainability

Recent data indicates that global temperatures have reached unprecedented levels, with the 12-month average through April 2025 rising to 1.58°C above pre-industrial levels, surpassing the 1.5°C threshold set by the Paris Agreement . This change is accelerating the spread of dangerous fungal pathogens, posing serious health risks and threatening food security [11]. In Figure 1 I show the milestone through 2040 which is reported by The International Energy Agency [11]. Beyond immediate health and agricultural implications, global warming is reshaping the operational landscape for industries. Climate-related disruptions—such as extreme weather events, rising sea levels, and water scarcity—are placing significant stress on global supply chains and manufacturing ecosystems. In response, a global energy transition is underway, pushing industries to reduce carbon footprints, adopt renewable energy, and embrace sustainability as a core design principle. By 2040, high-tech enterprises will be expected to meet stringent environmental regulations, implement circular economy practices, and leverage green technologies such

as smart grids, carbon capture, and low-impact materials. Sustainability will no longer serve as a competitive advantage but rather as a prerequisite for market access, investor confidence, and social acceptance.

Technological Convergence and the Impact of AI

By 2040, technological convergence—driven by the integration of artificial intelligence with

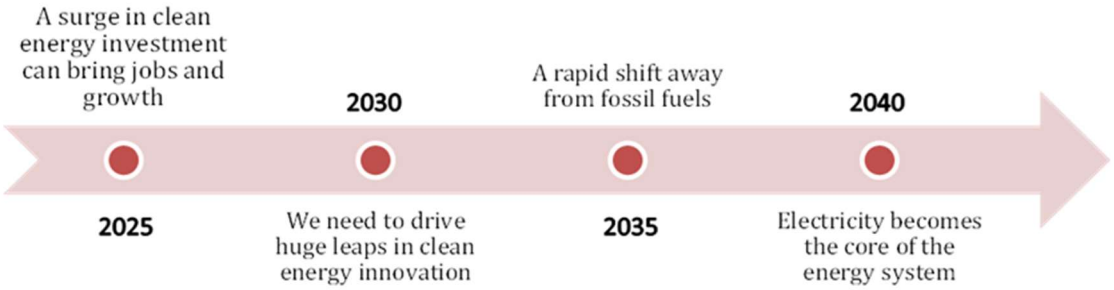

Figure 1: Roadmap's key milestones for sustainability through 2040

complementary fields such as robotics, quantum computing, biotechnology, advanced materials, and the Internet of Things (IoT)—will redefine industrial systems and product realization. AI will no longer be a stand-alone tool; it will act as the connective tissue across cyber-physical-social systems, enabling predictive analytics, autonomous decision-making, and real-time data monitoring in design and manufacturing. High-tech enterprises will rely on AI not only for operational efficiency but also for generative design, human-AI collaboration, adaptive supply chains, and continuous learning systems. Companies that can strategically harness this convergence will gain exponential advantages in productivity, responsiveness, and market differentiation.

The Impact of Social Media and Consumer Behavior

Consumers will be more digitally empowered, socially connected, and influential than ever before. Social media platforms will continue to evolve into powerful ecosystems where users shape brand narratives, demand transparency, and co-create products in real-time. The line between producers and consumers will blur as user-generated content, peer reviews, and digital activism influence purchasing decisions and corporate accountability. For high-tech enterprises, success will hinge on their ability to respond to rapidly shifting expectations, engage in continuous dialogue with customers, and build trust through openness and shared values.

Cybersecurity and Ethical/Regulatory Governance

In 2040, cybersecurity and ethical governance will be critical for high-tech enterprises operating in hyperconnected, AI-driven environments. As smart factories and digital twins exchange sensitive data across global networks, the risk of cyberattacks and data breaches will escalate [12]. Simultaneously, growing concerns over algorithmic bias, surveillance, and data privacy will demand transparent AI governance and compliance with evolving international regulations. Enterprises must embed cybersecurity and ethics into their core systems while maintaining agility to adapt to shifting legal and societal expectations. Having established foundational definitions (Section 1.1) and explored, through my speculation, the key contextual factors shaping the world of 2040 (Section 1.2), I now present the defining characteristics of a successful high-tech enterprise in that future landscape in Section 2.

2. Characteristics of a Successful High-Tech Enterprise in 2040

Building on the foundational definitions and contextual analysis presented in Section 1, I now synthesize these insights to identify the key characteristics of a successful high-tech enterprise in 2040. These characteristics are summarized in Table 1 to provide a clear, structured view of the strategic capabilities required to thrive in the future global landscape.

Table 1: Characteristics of a Successful High-Tech Enterprise in 2040

Dimension	Key Characteristic	Rationale Based on Section 1
Technological Core	Integration of AI and advanced digital technologies	Reflects the definition of high-tech enterprises and the role of AI-driven convergence
Global Operating Model	Distributed design and production networks	Aligned with global value chains (GVCs) and innovation networks
Dual-Market Competitiveness	Strong presence in both domestic and international markets	Based on the need to succeed locally and globally through innovation, cost efficiency, and regulatory adaptation
Workforce Adaptability	Continuous reskilling, human-AI collaboration, inclusive labor practices	Driven by evolving labor demographics and automation trends
Geopolitical Resilience	Supply chain diversification, localization readiness, and agility	Responds to global instability, protectionism, and strategic autonomy trends
Sustainability Integration	Carbon-neutral operations, circular economy, and green innovation	Required due to climate change, energy transition, and stakeholder expectations
Consumer-Centric Strategy	Real-time engagement, personalization, and ethical branding	Reflects social media influence, demand for transparency, and co-creation trends
Cybersecurity & Ethical Governance	Secure-by-design systems and adaptive compliance with global regulations	Required due to digital vulnerabilities and rising expectations for AI transparency and data protection
Food and Resource Awareness	Strategic alignment with agri-tech, circular resource use, and supply resilience	Necessary to address food insecurity, population growth, and sustainability challenges

Table 1 presents the core focus areas and requirement list that high-tech enterprises must fulfill to succeed by the year 2040. These characteristics serve as strategic targets for future readiness. In the next section, I identify key challenges and issues that may hinder progress toward achieving this vision.

3. Key Challenges

While the characteristics outlined in Table 1 define the strategic goals for a successful high-tech enterprise in 2040, realizing them will not be without obstacles. Each focus area comes with specific

technical, organizational, or societal challenges that could hinder progress. Table 2 summarizes these key barriers, highlighting areas where proactive planning, innovation, and policy interventions are most needed.

Table 2: Key Challenges Corresponding to Future Enterprise Characteristics

Characteristic (from Table 1)	Corresponding Challenge
Integration of AI and advanced technologies	High costs, lack of interoperability, and resistance to AI integration across legacy systems
Distributed design and production networks	Complex coordination, IP protection, and geopolitical constraints on global operations
Strong domestic and global competitiveness	Trade uncertainty, regulatory fragmentation, and increasing global competition
Continuous reskilling and inclusive labor	Skills gap, digital illiteracy, and uneven workforce access to AI training
Supply chain diversification and agility	Supplier risks, geopolitical disruptions, and cost inefficiencies in redundant systems
Carbon-neutral and circular economic practices	High implementation costs, slow regulatory adaptation, and technological limitations in green innovation
Real-time engagement and ethical branding	Risk of misinformation, data misuse, and difficulty maintaining consistent brand values across regions
Secure-by-design and adaptive compliance	Escalating cybersecurity threats, lack of harmonized global standards, and AI governance complexity
Agri-tech and circular resource alignment	Inadequate innovation in food-tech, water scarcity, and logistical constraints in resource recovery systems

Following the identification of these key challenges, in Section 4 I will critically evaluate their root causes and interdependencies to uncover potential solutions. This is the foundation for proposing a strategic framework to address the 2040 requirement list.

4. Potential solutions

To begin Section 4, I first introduce key foundational concepts that are essential for understanding the proposed solutions. Specifically, I focus on the principles of Industry 5.0 and Evolving Cyber-Physical-Social Systems (E-CPSS), as they provide the conceptual foundation for the strategic framework I propose. The potential solutions to the previously identified challenges are developed within this context, aiming to align technological advancement with human-centric, resilient, and sustainable enterprise transformation by 2040.

Industry 5.0, Sustainability, Human-Centric, and Resilience

The evolution of industry has progressed through distinct phases: Industry 1.0 introduced mechanization via steam and waterpower; Industry 2.0 brought electricity, mass production, and assembly lines; and Industry 3.0 added computers, automation, and electronics—each advancing productivity and efficiency. Today, we are in the era of Industry 4.0, marked by AI, IoT, cyber-physical systems, machine learning, and smart, connected manufacturing. I illustrate this progression in Figure 2. Industry 5.0 is a framework for

re-imagining the future of energy, manufacturing, mobility, and supply chains that build upon and complement the meaningful groundwork paved by the vision of Industry 4.0. Industry 5.0 uses collaborative robots and artificial intelligence to bring a human touch to the concept of digital transformation. Promoted by the European commission and other governmental bodies, Industry 5.0 emphasizes a triple-bottom-line of economic, environmental, and societal impact, bringing ESG (Environment, Social and Governance) perspective and balance to what have often been technology-led and economic-driven choices [13], [14].

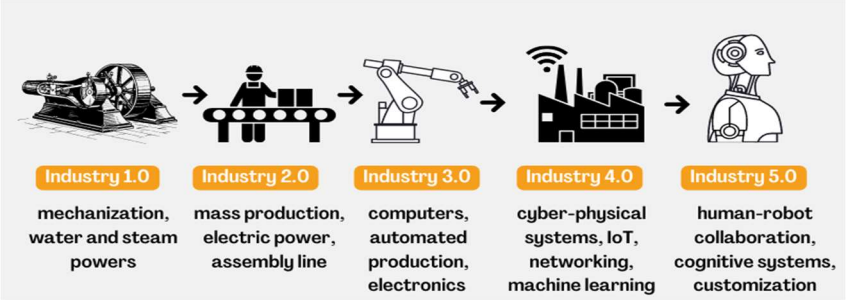

Figure 2: Evolution of Industry in Phases of Industrialization [14]

Evolving Cyber-Physical-Social System

A Cyber-Physical-Social System (CPSS) is *"a system comprising cyber, physical, and social components, which exists or emerges through the interactions between these components."*

One of the key features of CPSS is that the form, structure, and interactions constantly evolve to meet changes in the environment. Designing evolving CPSS involves making tradeoffs among the cyber, physical, and social systems, where human stakeholders are integral to system effectiveness. These systems adapt dynamically using recursive feedback from environmental data to guide controlled evolution [15], [16]. Industry 5.0 builds upon Industry 4.0 by integrating collaborative intelligence between humans and machines, while E-CPSS highlights the dynamic interplay between cyber, physical, and social components. By reflecting on both, we can create a framework for high-tech enterprises aiming to thrive in a complex and rapidly changing global landscape.

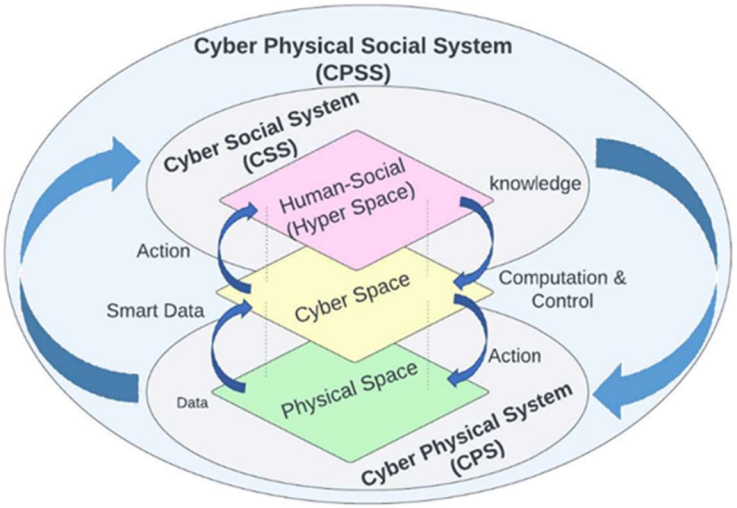

Figure 3: The Cyber Physical Social System (CPSS) ecosystem [16]

Figure 3 illustrates the dynamic structure of a Cyber-Physical-Social System, highlighting the interconnectedness of its three core layers: Physical Space, Cyber Space, and Human-Social Space.

4.1. Proposed Solution Framework Ties to Industry 5.0 and E-CPSS

To meet the requirement list outlined in Section 2 and address the challenges identified in Table 2, I propose a strategic solution framework grounded in the principles of Industry 5.0 and Evolving Cyber-Physical-Social Systems (E-CPSS). These two foundations emphasize the importance of aligning technological advancement with human-centricity, adaptability, systemic resilience, and sustainability. The proposed framework aims to position the enterprise not just as a smart production system, but as an adaptive socio-technical ecosystem capable of thriving in the complex global landscape of 2040. A core element of this framework is the decentralization of the enterprise into a network of interconnected micro-enterprises. Rather than relying on a single centralized structure, the enterprise is reorganized into multiple units distributed across different geographic and regulatory environments. This approach increases agility and resilience—enabling the enterprise to adapt to geopolitical constraints, reduce vulnerability to localized disruptions, and tap into the unique strengths of different regions. For instance, one country may offer access to advanced technological infrastructure, another to more affordable clean energy, and another to a highly skilled or cost-effective workforce. Additionally, cultural variation can be addressed more effectively by tailoring local customer-facing services, enabling the enterprise to be globally distributed yet locally adaptive. To support such decentralized operations, the framework incorporates a layered hybrid connectivity model. While outer-facing components of each micro-enterprise remain connected in real-time to global markets and resources, the core systems operate with restricted access—only synchronizing after passing through rigorous validation layers such as AI-based firewalls or approval protocols. This balances cybersecurity risk mitigation with the need for adaptability and responsiveness. Further, this framework treats the enterprise as an interdisciplinary ecosystem—not merely a production system, but one that actively contributes to solving broader challenges such as sustainability, clean energy, and food and water resilience. In this view, business models should incorporate clean energy production, smart agriculture, and circular resource management as part of the enterprise's value-creating processes. Recent initiatives by companies like Tesla exemplify this shift toward enterprises that also act as sustainability platforms [17]. From a decision-making perspective, one of the important questions we should ask is "what we are trying to model and optimize today may no longer exist tomorrow?". The enterprise operates within an evolving cyber-physical-social context where static models quickly become obsolete. Therefore, it adopts satisficing-based strategies, such as Compromise Decision Support Problems (cDSP), to guide decision-making under uncertainty and continuous change [18], [19]. These approaches support adaptive trade-offs among competing objectives, accounting for the fluid and interconnected nature of future systems. Lastly, the success of this human-centered enterprise depends on equipping its workforce with the mindset and skills for human-AI collaboration. Industry 5.0 explicitly emphasizes the co-evolution of humans and machines, where humans are not replaced by AI, but by those who fail to learn how to work with it. To that end, enterprises must invest in continuous education and upskilling, empowering employees to harness AI and intelligent systems as productivity partners rather than competitors. Equally important is the creation of a work environment that fosters happiness, creativity, and meaningful collaboration. As AI reshapes communication structures and workflows, the risk of diminished human connection could weaken team

cohesion and trust. Therefore, attention to workforce well-being and satisfaction is not just an ethical imperative—it is a strategic one. A healthy and happy workforce, with opportunities for personal and professional growth, will be more value to the enterprise in 2040.

4.2. Visualizing the Strategic Framework

To better illustrate the solution proposed in Section 4.1, Figure 4 presents a visual representation of the strategic framework for a 2040 high-tech enterprise. This framework is conceptualized as an Evolving Cyber-Physical-Social System (E-CPSS)—a dynamic, interconnected environment shaped by external forces such as technological evolution, environmental pressure, geopolitical volatility, and social and workforce shifts. These external conditions continuously influence the enterprise, requiring systemic adaptability and responsiveness.

Within this evolving context, the inner layer of the framework is grounded in Industry 5.0, which introduces key operational strategies aimed at resilience and human-centric innovation. These include:

- the decentralization into micro-enterprises for geopolitical and operational flexibility,
- adaptive decision-making using satisficing strategies (e.g., cDSP),
- hybrid connectivity with cybersecurity protocols, and
- a focus on workforce well-being and sustainable value creation.

At the core of the framework lies Human-AI Collaboration, which serves as the central enabler for intelligent, adaptive, and ethical enterprise functioning. This core reflects the Industry 5.0 vision, where humans are empowered—not replaced—by technology, and where collaboration between humans and AI systems drives long-term value. In summary, Figure 4 integrates theoretical foundations with practical, future-oriented strategies that respond to the challenges identified in Section 3.

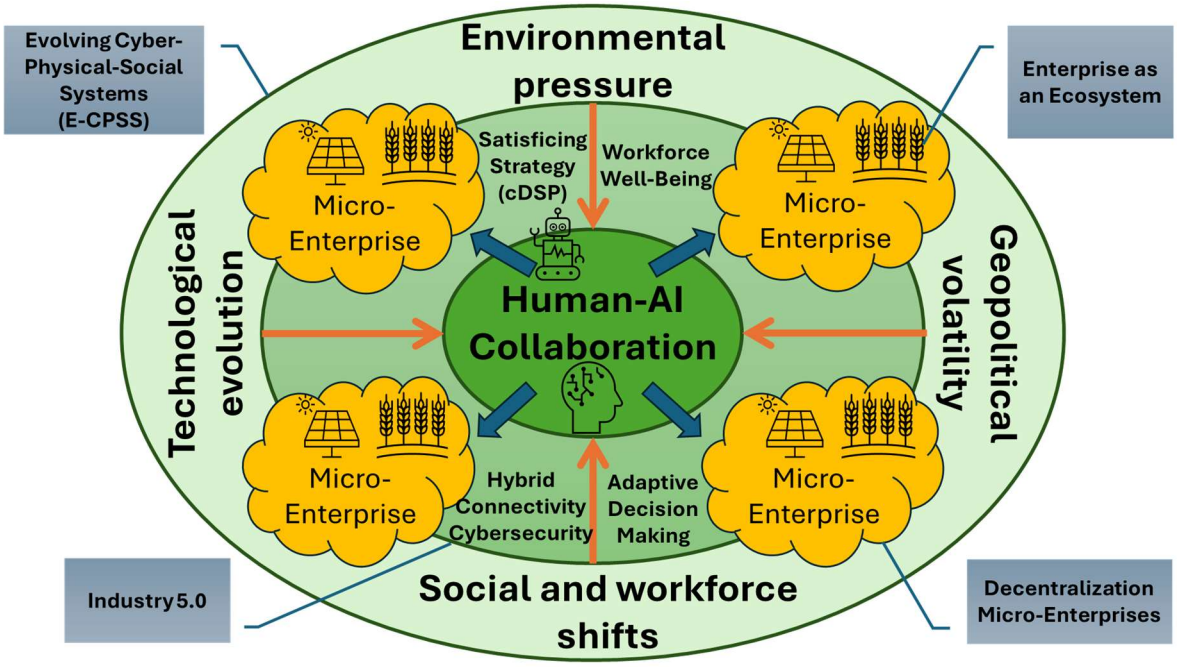

Figure 4: Strategic Framework for a 2040 High-Tech Enterprise as an E-CPSS

5. Issues Worthy of Investigation or Future Researches

As enterprises evolve within increasingly complex and dynamic environments, several critical areas emerge that warrant further investigation. The following topics highlight key directions for future research to support high-tech enterprises in achieving sustainable, resilient, and human-centered growth by 2040.

Social Acceptance and Human-Centered Design in CPSS

Successful deployment of CPSS-based solutions depends on human trust and usability. If humans are not fully considered as both **users** and **information providers**, applications may fail to gain acceptance. Research is needed to develop human-centered interfaces and participatory design methods that align with diverse user expectations, in other words, different stakeholders.

Quantifying the Effectiveness of Human-AI Collaboration

As Human-AI Collaboration becomes central to Industry 5.0, future research should explore metrics and frameworks for evaluating the effectiveness of this collaboration in terms of productivity, innovation quality, and workforce well-being.

Resilience Modeling in Evolving CPSS

Evolving cyber-physical-social systems (E-CPSS) introduce uncertainty due to rapid feedback and adaptation. Future work should focus on dynamic modeling approaches that integrate real-time data to assess and strengthen system resilience under evolving conditions.

Governance and Ethical Frameworks for Decentralized Micro-Enterprises

While decentralization enhances resilience and adaptability, it raises new challenges in governance, coordination, and accountability. Research is needed to develop robust models for ethical governance across distributed, semi-autonomous enterprise units.

Education Models for AI-Augmented Workforce Development

Investigating scalable, inclusive, and lifelong learning strategies for equipping the future workforce with AI collaboration skills is essential. This includes rethinking training in ecosystems, certification systems, and human-machine team design.

6. Closing Remarks

In this essay, I explored the transformation of a global manufacturing enterprise into a human-centered and technologically advanced system by 2040. Grounded in the principles of Industry 5.0 and Evolving Cyber-Physical-Social Systems (E-CPSS), the framework presented here will be a foundational step toward imagining how enterprises might adapt to increasing complexity, uncertainty, and interconnectedness. While not exhaustive, it optimistically outlines a potential pathway for aligning technological innovation with human values, sustainability, and systemic resilience. This work is intended as a starting point for deeper investigation and future research in designing enterprises as an E-CPSS for the future.

7. Acknowledgments

This essay is submitted alongside my participation in IDETC 2025, where I will also be presenting as a co-author of the accepted papers DETC2025-167668, DETC2025-169010, and DETC2025-168932. I have used ChatGPT selectively to improve clarity and readability and the ideas presented in this essay are based on my speculation.

8. References

[1] "Optimizing digital transformation with technology and talent," World Economic Forum. Accessed: May 07, 2025. [Online]. Available: https://www.weforum.org/stories/2024/09/unlocking-the-full-potential-of-digital-transformation-through-technology-and-talent/

[2] X. Xu, Y. Lu, B. Vogel-Heuser, and L. Wang, "Industry 4.0 and Industry 5.0—Inception, conception and perception," *Journal of Manufacturing Systems*, vol. 61, pp. 530–535, Oct. 2021, doi: 10.1016/j.jmsy.2021.10.006.

[3] "The links between global value chains and global innovation networks: An exploration," OECD Science, Technology and Industry Policy Papers 37, Apr. 2017. doi: 10.1787/76d78fbb-en.

[4] R. Harte, L. Puccio, M. Szczepanski, and European Parliament, Eds., *Interactions between trade, investment and trends in EU industry: EU regions and international trade: in-depth analysis*. Brussels: European Parliament, 2017. doi: 10.2861/07338.

[5] H. Ataburo, G. E. Ampong, and D. Essuman, "Developing operational resilience to navigate transportation disruptions: the role and boundaries of efficiency priority," *Ann Oper Res*, vol. 340, no. 2, pp. 723–755, Sep. 2024, doi: 10.1007/s10479-024-06092-4.

[6] United Nations, Department of Economic and Social Affairs, Population Division, "World Population Prospects 2024." 2024.

[7] H. Ritchie, "The UN has made population projections for more than 50 years – how accurate have they been?," *Our World in Data*, Jun. 2023, Accessed: May 07, 2025. [Online]. Available: https://ourworldindata.org/population-projections

[8] "How_to_Feed_the_World_in_2050.pdf." Accessed: May 07, 2025. [Online]. Available: https://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

[9] "How are geopolitical risks affecting the world economy?," Economics Observatory. Accessed: May 07, 2025. [Online]. Available: https://www.economicsobservatory.com/how-are-geopolitical-risks-affecting-the-world-economy

[10] Sunny Jiang, Yesilernis Pena, Dell Gines, Todd Lang, and Melanie Hwang, "Artificial Intelligence Impact on Labor Markets - International Economic Development Council," International Economic Development Council, Literature Review. Accessed: May 08, 2025. [Online]. Available: https://www.iedconline.org/edrp-reports/ai/artificial-intelligence-impact-on-labor-markets/

[11] "Net Zero by 2050 – Analysis," IEA. Accessed: May 08, 2025. [Online]. Available: https://www.iea.org/reports/net-zero-by-2050

[12] Jeremy Jurgens and Kelly Bissell, "Global Cybersecurity Outlook 2022," World Economic Forum, 2022. Accessed: May 08, 2025. [Online]. Available: https://www.weforum.org/publications/global-cybersecurity-outlook-2022/

[13] Momenta, "Industry 5.0 | Industry 5.0 Strategy | Industry 5.0 Technologies." Accessed: May 08, 2025. [Online]. Available: https://www.momenta.one/industry5.0

[14] J. Matuszak, "Is Your Business Ready for Industry 5.0?," KnowHow. Accessed: May 08, 2025. [Online]. Available: https://knowhow.distrelec.com/manufacturing/is-your-business-ready-for-industry-5-0/

[15] J. K. Allen, A. B. Nellippallil, Z. Ming, J. Milisavljevic-Syed, and F. Mistree, "Designing Evolving Cyber-Physical-Social Systems: Computational Research Opportunities," *Journal of Computing and Information Science in Engineering*, vol. 23, no. 060815, Aug. 2023, doi: 10.1115/1.4062883.

[16] S. Pasandideh, P. Pereira, and L. Gomes, "Cyber-Physical-Social Systems: Taxonomy, Challenges, and Opportunities," *IEEE Access*, vol. 10, pp. 42404–42419, 2022, doi: 10.1109/ACCESS.2022.3167441.

[17] "Gigafactory Texas," *Wikipedia*. Apr. 18, 2025. Accessed: May 10, 2025. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Gigafactory_Texas&oldid=1286290149

[18] L. Guo, J. K. Allen, and F. Mistree, "Optimize or satisfice in engineering design?," *Res Eng Design*, vol. 35, no. 3, pp. 239–267, Jul. 2024, doi: 10.1007/s00163-023-00431-5.

[19] S. Mandegari, M. J. Bhalerao, J. K. Allen, and F. Mistree, "Predicting Future States of Evolving Systems," presented at the ASME 2024 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, American Society of Mechanical Engineers Digital Collection, Nov. 2024. doi: 10.1115/DETC2024-146340.