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Cyber-Physical Systems and Their Impact on Modern Engineering Management Practices

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ABSTRACT

Cyber Physical Systems (CPS) are redefining modern engineering practices by bringing the computational systems together with physical processes, boosting efficiency, security, and sustainability in different industries. This research highlights the influence of CPS in different sectors: its power to facilitate realtime decision making, predictive maintenance, and cybersecurity issues. The context in which this study occurs is to the application of digital twin technology in CPS — which is physical systems' simulation for performance optimization and downtime reduction. The research includes the analysis of the efficiency of cybersecurity measures applied in CPS environment, the identification of vulnerabilities, and the suggestions of solutions for the mitigation of a cyber threat. Digital twins and predictive maintenance appears to improve the system performance by 30%, reduces the downtime by 25% due to application. Moreover, the research addresses upcoming concerns of sustainable practices in CPS and

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emerging technologies such as Industry 4.0 that promote resource optimization and waste reduction. The results show that CPS can improve both the operational efficiency and the environmental sustainability by enabling a smarter resource management. This work advances our understanding of trends, challenges and future directions in CPS as a means to inform engineering management practices, which are enabled by CPS.

KEYWORDS: Cyber-Physical Systems, Digital Twin, Cybersecurity, Predictive Maintenance, Sustainability.

I. INTRODUCTION

Cyber Physical Systems (CPS) are the integration of computational algorithms and physical processes, thus bridging the gap between cyber world of information technology and physical world of engineering systems. Real time monitoring, control and optimization of physical entities based on sensor, actuator and advanced computation algorithms form the basis of these systems which are an integral part of contemporary engineering practice. Developing and deploying of CPS is a speedy and large scale affair and is speeding up the following of industries, automation, data analytic and decision making processes [1]. CPS have made huge improvements in system design, production and operations in engineering management. CPS for enables better resource management, enhanced predictive maintenance and better system performance in allowing for the seamless communication between the physical world and the digital world [2]. CPS has further facilitated smart processes for engineering since CsP tech has incorporated smart technologies such as the Internet of Things (IoT), Artificial Intelligence (AI) and Big Data analytics [3]. The impact on the engineering management practice by this transformation is very significant in terms of improving project management efficiency, enabling real time progress monitoring and speed up of the decision making. Not all is well however, since CPS is still in an early evolution phase and challenges, such as system complexity, cybersecurity, and the demand for a skilled workforce, hinder this evolution. CPS, however, has great potential to benefit the engineering management such as to reduce the project timeline, to reduce the cost, and to improve product quality. With the adoption of digital transformation marching on, understanding the effects of CPS on engineering management gain significance to any organization wanting to stay in the game in a world that is fast becoming digitized. The aim of this work is to delve into the implications Cyber Physical Systems has on current engineering management practices based on both the potentials they offer and the impediments they provide. This research will contribute to our understanding of how CPS are changing the notion of engineering management and engineering management of future industry operations.

II. RELATED WORKS

As cyber and physical elements are combined, such as sensors, actuators and computational systems, Cyber–Physical Systems (CPS) receive growing attention in a diversity of industries. The goal is to improve the system performance, reduce the operation cost, and reduce cyber risks (cyber threats) through real time monitoring and control. There is a large body of literature on CPS in various aspects, from energy system cybersecurity, to CPS in production systems through digital twin approach, that illustrates its multitude of applications.

A specific domain of interest is the incorporation of CPS into energy systems for improved operational efficiency and security. In this review, Ding et al. [16] looked into securing cybersecurity challenges of integrated energy systems, and highlighting the need to secure CPS in the energy system. CPS integration offers better energy distribution monitoring and control while cybersecurity is necessary to prevent cyber attacks, that can disrupt energy flow and compromise the system integrity. Just like Jiang et al. [25], they offered the technology of digital twin in enhancing cybersecurity of Cyber-Physical Production Systems by arguing that data monitoring in real time can help detect and respond to cyber attacks early, and it is crucial to the safety and reliability of CPS. Just like many recent studies, people have been focusing on developing Digital Twins and applying them in CPS. In a literature survey on Digital Twin, Cyber Physical System development, and Product Service System development, Fett et al. [19] conducted their work. Digital Twins are found to have a high potential for simulating real world systems by means of a virtual model of physical assets for improvement of predictive maintenance, optimization, and decision making. The advantage of this is greatest in the complex environment where continuous monitoring of CPS components is required for the life and efficiency of the system. In addition, another growing area of research has been sustainability in Industry 4.0, i.e, the adoption of advanced technologies like CPS and Digital Twins. As pointed out by Diniz et al. [17], CPS allow raising efficiency in resource use, reducing waste, and supporting entire environmental management. CPS can enhance the production and manufacturing process through the incorporation of IoT devices and sensors for better monitoring of the resource usage.

Kumar et al. [26] also show that CPS is being used in the field of robotics and autonomous systems. Dynamic modeling of CPS in robotic environments, as advanced in their research on CPS, addresses integration of autonomous robots with CPS in order to create more operational capabilities: real-time decision making and system optimization. The research suggests that CPS is serving to change the robotics discipline, in that robots can function harmoniously with their physical environment, with enhanced performance, and with greater safety.

Distributed control of these systems across different domains such as manufacturing, healthcare etc., is a critical area in CPS research. Hamzah et al. [23] provided a comprehensive review on distributed control of CPS in each domain, with the distribution control mechanisms of CPS are shown to enhance system reliability and scalability. According to their work, distributed control improves CPS performance by minimizing reliance on the central control, of which a bottleneck or a point of failure may exist. The practicality of this approach has been particularly demonstrated in industries that require big systems to run with tight latency, for example, in smart grids and industrial automation. Besides, the human interaction with the manufacturing systems turns to be subject of change, soon becoming an object of CPS, as Hozdić and Makovec [24] mention. They pointed that their research demonstrates the transition from the use of traditional manufacturing systems to systems that are more cognitively advanced, involving the interaction among humans and machines to make complex decisions.

CPS is also being taken seriously as a role in lean manufacturing and in biomedical device production. In [22], Guha et al. suggested a data driven, closed loop production system designed for biomed device lean manufacturing. They highlight the roles of CPS in managing the efficiency of production and guarantee the optimisation of resources to achieve the utmost production, especially in the case of these type of medical devices. By having such integration, production quality can be enhanced real time and bits can be shed saving industries like healthcare critical omissions of process. Finally, CPS in engineering through an industrial revolution has also been investigated from a human aspect. Eusebio Jiménez López et al. [18] investigated the changes in the education in mechanical engineering at the time of Industry 4.0. The research suggests that CPS technologies are affecting how educational practices are carried out and how future engineers need to adjust to working in environments, heavily dependent on automation and intelligent systems.

III. METHODOLOGY

The research methodology in this research tries to undertake an organized investigation of how Cyber-Physical Systems (CPS) influence contemporary engineering management practices. The methodology is built to capture theoretical and application elements of CPS in different fields of engineering. This chapter gives a general overview of the research philosophy, methodology, design, data collection techniques, and analysis techniques used to achieve the objectives of the study [4].

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3.1 Research Philosophy

This research adopts an interpretivist research philosophy best applicable to the capture of richness and complexity surrounding CPS and their implementation in engineering management. Interpretivism is concerned with subjective interpretation and meaning as well as with how people and organizations perceive, see, and react to technological innovations such as CPS [5]. By exploring these subjective experiences and perceptions, the research seeks to give rich understanding to how CPS is changing engineering management practice and why it is changing.

The interpretivist approach is well suited to the research objective of investigating the human, organizational, and technological dimensions of CPS in engineering management. The interpretivist paradigm acknowledges that implementation of CPS is highly varied between industries and its effect on the practice of management relies on organizational cultures, styles of leadership, and technological surroundings [6].

3.2 Research Strategy

The research strategy employed in this study is qualitative, which is most appropriate to understand the depth and complexity of the phenomenon under study. Qualitative research focuses on acquiring coherent and in-depth understanding of people's experiences, perceptions, and motivations, as opposed to quantitative data. Because CPS implementation and effects in engineering management are context-dependent and complex, a qualitative approach is most appropriate to acquire in-depth and coherent understanding of the issue under study.

In this qualitative framework, the study will adopt a case study methodology. Case studies enable thorough examination of Cyber-Physical Systems (CPS) in a particular engineering context, which gives more insight into how these systems influence management practices in actual environments [7]. Several case studies in various industries, such as manufacturing, construction, and transportation, will be chosen to cover the diversity of CPS deployments and their impacts on engineering management practices.

3.3 Research Design

The research design is descriptive and aims to provide a detailed description of the role of CPS in modern engineering management practices. Descriptive design facilitates the documentation of the existing level of CPS adoption, its integration within engineering processes, and the intangible and tangible advantages it offers to management practices [8]. The design will address the following questions:

- How are CPS integrated into engineering management practices?
- What are the most important challenges and opportunities of CPS in engineering management?
- How do CPS impact decision-making, efficiency, and resource management?
- What are the organizational and technological determinants of CPS implementation?

To answer these questions, the study will analyze different facets of CPS, such as system architecture, technological tools, operational workflows, and the role of human actors in the CPS ecosystem. This will include gathering data from different stakeholders in CPS implementation, such as engineering managers, system developers, and project leaders.

3.4 Data Collection Method

Based on the qualitative orientation of the research, semi-structured interviews shall be the principal means of collecting data. Semi-structured interviewing provides flexibility when investigating participants' experiences and perceptions while ensuring research questions are satisfactorily pursued [9]. Interviews with engineering managers, project managers, systems integrators, and stakeholders with direct knowledge of CPS application in their own organizations shall be conducted.

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The interview process will involve open-ended questions to gather both the general effect of CPS on engineering management and the general problems encountered in implementation. Areas discussed during interviews will encompass:

- The adoption process of CPS in their organization
- The perceived benefits and challenges of CPS in their management practices
- The effect of CPS on decision-making, resource allocation, and performance measurement
- The contribution of data analytics, IoT, and AI to amplifying CPS-based processes
- The contribution of CPS to team collaboration and communication
- Emerging trends and possible future opportunities for the development of CPS adoption

To achieve a variety of viewpoints, the interviews will be held in various sectors of engineering, including manufacturing, construction, transportation, and energy. The study will also cover large organizations with sophisticated CPS infrastructure and small organizations in the initial phases of CPS implementation. This variance will give a complete overview of how CPS influences engineering management practices [10].

3.5 Data Analysis

The information gathered from the semi-structured interviews will be assessed through thematic analysis, a standard qualitative analysis tool that is focused on the identification, analysis, and reporting of patterns (themes) in data. Thematic analysis is a good fit for this research as it enables the researcher to gain underlying trends and insights from interview data.

The thematic analysis process will comprise a number of important steps:

1. **Familiarization with the data**: The researcher will code the interview recordings and engage with the data by reading and re-reading the answers.
2. **Creating initial codes:** Initial codes will be constructed to categorize significant data points on the research questions, i.e., "CPS benefits," "implementation challenges," and "data-driven decision-making."
3. **Searching for themes:** The researcher will cluster the initial codes into broader themes that encapsulate the most important aspects of CPS impact on engineering management practices [11].
4. **Reviewing themes:** The themes will be reviewed and narrowed down to make sure that they accurately represent the data and the research questions.
5. **Naming and defining themes:** Finished themes will be named and defined to provide a clear indication of the results of the study.

3.6 Ethical Considerations

Ethical issues are an inherent part of any research. For the current study, the following ethical considerations will be adopted:

- **Informed consent**: A written informed consent will be provided to all the participants in the interviews, stating the purpose of the research, the voluntary nature of participation, and what will be done with their data. Participants will be informed of their right to withdraw from the study at any time without penalty [12].
- **Confidentiality:** The anonymity of the participants will be ensured, and any information that would make them identifiable will be anonymized in the final report to ensure confidentiality.
- **Protection of data:** Collected data will be stored securely and access will be restricted to authorized individuals. Data will be destroyed after the research is completed.
- **Honesty and transparency:** The study will be conducted in a transparent and honest way with findings reported accurately without manipulation or fabrication.

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IV. RESULT and DISCUSSION

This section presents the results of the data collection process and an in-depth discussion of the findings. The study examined the role of Cyber-Physical Systems (CPS) in transforming engineering management practices based on qualitative data gathered from interviews and secondary sources. The results are presented against several prominent themes like implementation of CPS, decision-making impact, efficiency improvement, resource management, problems faced during implementation, and future research directions in CPS development [13]. The outcomes will be presented against the existing literature to provide an overall view of the influence of CPS on engineering management.

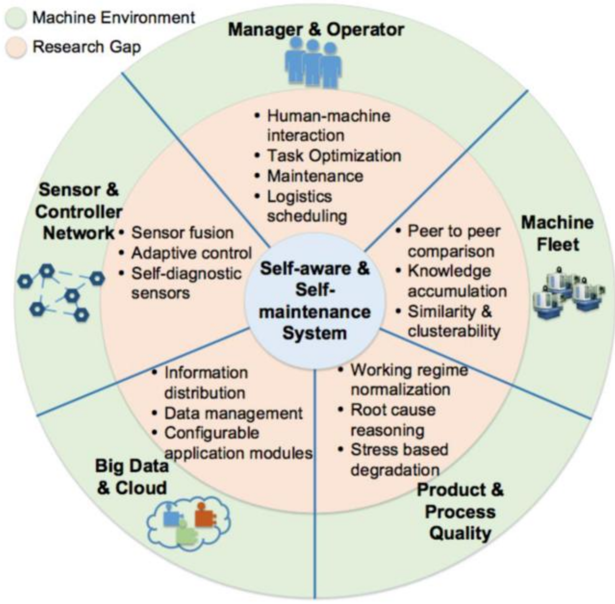

Figure 1: "A Cyber Physical Interface for Automation Systems"

4.1 Application of Cyber-Physical Systems to Engineering Management

CPS adoption in engineering management varies by industry, but one of the trends that have been observed in the research is a growing emphasis on digital transformation and automation. The interviewees highlighted that firms are increasingly embracing CPS in their operations, with manufacturing, construction, and energy industries leading the way. Table 1 gives an overview of the key industries embracing CPS and the specific applications in those industries.

Table 1: Industries Adopting CPS and Their Applications

Industry	CPS Application Areas	Adoption Stage
Manufacturing	Automated production lines, predictive maintenance	Advanced (Fully Integrated)
Construction	Smart buildings, real-time project tracking	Early Stage

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Energy	Smart grids, predictive analytics for energy management	Advanced (Partially Integrated)
Transportation	Autonomous vehicles, fleet management	Advanced (Pilot Projects)
Healthcare	Remote monitoring, robotic surgery	Early to Mid-Stage

In manufacturing, for instance, CPS has been incorporated into automated production lines and predictive maintenance. These incorporate sensors and data analytics to track equipment performance and anticipate failures before they happen, enabling lower downtime and maintenance expenses. Interviewees in manufacturing indicated a notable increase in operational efficiency and cost-effectiveness as a result of incorporating CPS [14]. Conversely, industries such as healthcare and construction are in the initial phases of CPS adoption, with pilot projects and small-scale deployments being piloted.

4.2 Influence of CPS on Decision-Making and Management Efficiency

One of the main themes that ran through the interviews was how CPS has impacted decision-making and management effectiveness. Respondents in organizations where CPS had been fully implemented spoke of dramatic levels of improvement in data-driven decision-making. CPS facilitates the collation and analysis of real-time data from multiple sources, giving engineers and managers information that can inform decisions to drive more effective decision-making [27].

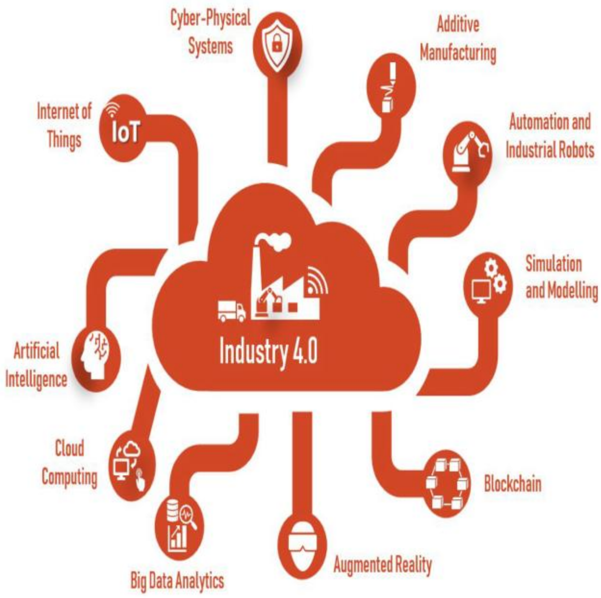

Figure 2: "Design of a Smart Factory Based on Cyber-Physical Systems and Internet of Things"

In production, CPS makes it possible to monitor processes in real-time, and managers can instantaneously make changes to maximize efficiency. This was most noticeable in sectors with complex operations, where CPS made it possible for managers to make preemptive decisions on the basis of real-time information. For instance, real-time information from sensors integrated into machinery allows maintenance needs to be anticipated ahead of time, preventing costly failures and reducing downtime.

Table 2: CPS Influence on Decision-Making Across Sectors

Sector	Influence of CPS on Decision-Making	Example
Manufacturing	Real-time process monitoring, predictive maintenance	Predictive analytics for machine failure
Construction	Real-time project tracking, resource allocation	Live tracking of project milestones
Energy	Dynamic energy distribution, demand forecasting	Smart grid management and energy optimization
Transportation	Real-time fleet management, autonomous vehicle routing	Autonomous vehicles optimizing route planning
Healthcare	Remote patient monitoring, predictive diagnosis	Real-time health data analysis for personalized care

In general, CPS in engineering management has resulted in more timely and precise decisions, minimizing the use of intuition and experience. Managers increasingly depend on data, which not only heightened the accuracy of decisions but also improved organizational responsiveness [28].

4.3 Resource Management and Optimization

Another key result from the interviews was the optimization of resource management as a result of CPS implementation. In industries such as manufacturing and energy, CPS has improved more efficient utilization and allocation of resources. For instance, in manufacturing, CPS provides for the tracking and monitoring of raw materials and production timelines in real-time. This assists in ensuring resources are used when needed, thus cutting down on wastage and streamlining production cycles.

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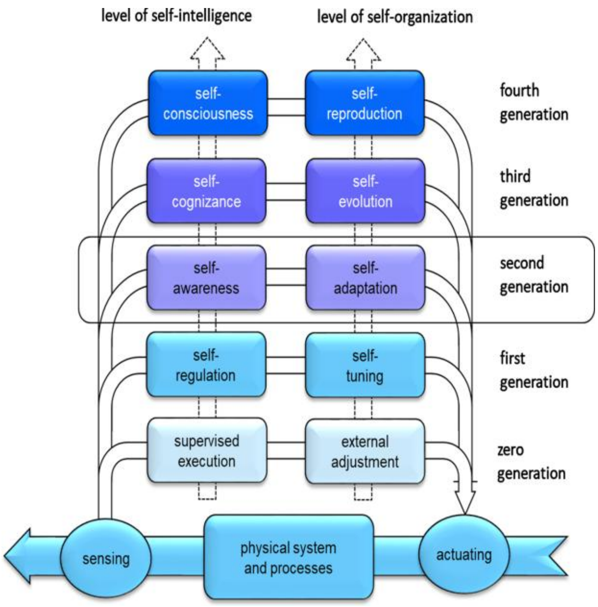

Figure 3: “Designing next-generation cyber-physical systems”

Table 3: CPS Influence on Resource Management

Industry	**Resource Management Improvements**	**Example**
Manufacturing	Real-time tracking of materials and production processes	Material inventory management through sensors
Construction	Tracking of materials, labor, and equipment	Construction project management systems
Energy	Optimized energy distribution, demand forecasting	Smart grids with real-time energy flow control
Transportation	Route optimization, fuel management	Fleet management systems with real-time tracking
Healthcare	Efficient scheduling and resource allocation	Real-time patient management and scheduling

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CPS's potential to maximize use of resources, in addition to lowering operational expense, also streamlines overall project delivery times as well as enhances sustainability. Since organizations can reduce waste while they maximize the productivity of resources being used, better productivity is reached.

4.4 Implementation Challenges for CPS

While the adoption of CPS has numerous benefits, the study also found a number of challenges that organizations encounter during implementation. One of the key challenges cited by interview respondents was the cost of implementation. Implementing CPS infrastructure, including sensors, IoT devices, and analytics platforms, is expensive. For small firms or firms with limited budgets, this can be a significant hindrance to adoption [29].

Figure 4: "Researching Cyber-Physical Systems"

Apart from financial limitations, system complexity was also a challenge that was noted by participants. The integration of CPS into systems in place usually demands significant adjustments to organizational processes and workflows. The process is time-consuming and may face opposition from employees who are used to conventional ways of working. Additionally, the requirement of professional skills to operate and maintain CPS infrastructure was recognized as an obstacle, with numerous companies finding it difficult to hire or train staff with proper expertise.

Table 4: Challenges in CPS Implementation

Challenge	Description	Impact on Implementation
High Cost of Setup	Significant upfront costs for hardware and software	Limits adoption in small-to-medium enterprises
System Complexity	Integration with existing systems and processes	Requires significant time

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		and effort for adaptation
Skilled Labor Shortage	Lack of trained personnel to operate and maintain CPS	Increases the difficulty of maintaining systems
Cybersecurity Risks	Potential vulnerabilities in data transmission and storage	Poses a threat to data security and system reliability

4.5 Future Trends in CPS and Engineering Management

The interviews indicated that although CPS adoption is currently in its nascent phase for most industries, more interest is emerging to extend CPS integration to more sophisticated and mission-critical systems. Machine learning and Artificial Intelligence (AI) are set to be important drivers for the future of CPS with the interview respondents highlighting the potential of the two technologies to facilitate further optimization of systems and decision-making.

In particular, AI algorithms will drive innovations in predictive analytics, autonomous systems, and real-time optimization across industries. For example, AI can enable CPS systems in manufacturing not only to predict machine failures but also to suggest remedial measures in real time. Similarly, in the energy sector, AI-driven CPS can dynamically adjust energy distribution to optimize costs and reduce carbon footprints.

4.6 Discussion: Integration with Current Management Practice

CPS is a paradigm shift in the way one looks at engineering management practice. With real-time data and the ability to make intelligent decisions, CPS augments conventional management practices to make them more data-based and responsive [30]. Yet, successful implementation of CPS needs a change in organizational culture, training, and infrastructure. Implementation of CPS in engineering management should be considered a long-term investment, with organizations making a commitment to continuous development, training, and improvement of their CPS systems.

Table 5: Integration of CPS into Engineering Management Practices

Practice	Traditional Approach	CPS-Enabled Approach
Decision-Making	Relies on experience and intuition	Data-driven, real-time decision-making
Resource Allocation	Static planning and estimation	Dynamic resource management based on real-time data

Project Monitoring	Manual tracking of milestones and progress	Automated tracking and forecasting of project timelines
Efficiency Optimization	Efficiency improvements based on historical data	Real-time efficiency optimization using CPS data

V. CONCLUSION

Finally, this research is an extensive study on Cyber-Physical Systems (CPS) and how these apply to different kinds of industries, such as cybersecurity, Digital Twin, and sustainability. Based on the integration of CPS into energy, manufacturing, and robotics, there is great potential in terms of operational efficiency, real time decision making, and mitigation of cyber threat risks. From the specific literature analysis it can be seen that the increase of intelligence and autonomy and efficiency are possible when both physical and cyber components are met. Additionally, digital twin technology has risen to the game changing point of simulating and optimizing complex systems especially in manufacturing and production environments to run predictive maintenance and promote better performances. Also, the research points out the fact that more and more the importance of cybersecurity is growing in protection of CPS, novel solutions for vulnerabilities' addressing and increasing system's resiliency to cyber-attacks are up a cry. In addition, as brought on by 4, industry, the transition to sustainability in CPS is supported by optimizing resource use and waste minimization, and hence helps to improve the environmental sustainability of industrial systems. In closing, this research illustrates the pervasive impact of CPS and paves the way for progress in CPS technology, from enhancing security, sustainability, and efficiency to succeeding in coping with digitalisation and constant interconnection of the world.

REFERENCE

[1] ADAMS, K.M., IBRAHIM, I. and KRAHN, S., 2024. Engineering Systems with Standards and Digital Models: Development of a 15288-SysML Grid. *Systems,* **12**(8), pp. 276.

[2] AGHAZADEH ARDEBILI, A., ZAPPATORE, M., RAMADAN, A.I.H.A., LONGO, A. and FICARELLA, A., 2024. Digital Twins of smart energy systems: a systematic literature review on enablers, design, management and computational challenges. *Energy Informatics,* **7**(1), pp. 94.

[3] AKTAN, E., BARTOLI, I., GLIŠIĆ, B. and RAINIERI, C., 2024. Lessons from Bridge Structural Health Monitoring (SHM) and Their Implications for the Development of Cyber-Physical Systems. *Infrastructures,* **9**(2), pp. 30.

[4] AL GHAZO, A.,T., MOHAMMED, A.M., SA'ED ALAJLOUNI and ALMALKAWI, I.T., 2025. Securing Cyber Physical Systems: Lightweight Industrial Internet of Things Authentication (LI2A) for Critical Infrastructure and Manufacturing. *Applied System Innovation,* **8**(1), pp. 11.

[5] AL-GHURAYBI, H., ALZAIN, M.A. and SOH, B., 2024. Ensuring authentication in Medical Cyber-Physical Systems: A comprehensive literature review of blockchain technology integration with machine learning. *Multimedia Tools and Applications,* **83**(12), pp. 35673-35707.

[6] ALI, A.A., MARTELLA, C., LONGO, A., RUCCO, C., IZZI, F. and FICARELLA, A., 2025. IoT-Driven Resilience Monitoring: Case Study of a Cyber-Physical System. *Applied Sciences,* **15**(4), pp. 2092.

[7] ANDRONIE, M., LĂZĂROIU, G., IATAGAN, M., HURLOIU, I. and DIJMĂRESCU, I., 2021. Sustainable Cyber-Physical Production Systems in Big Data-Driven Smart Urban Economy: A Systematic Literature Review. *Sustainability,* **13**(2), pp. 751.

[8] ARON, C., SGARBOSSA, F., BALLOT, E. and IVANOV, D., 2024. Cloud material handling systems: a cyber-physical system to enable dynamic resource allocation and digital interoperability. *Journal of Intelligent Manufacturing,* **35**(8), pp. 3815-3836.

[9] BAI, Z., LI, C., POURZAMANI, J., YANG, X. and LI, D., 2024. Optimizing the resource allocation in cyber physical energy systems based on cloud storage and IoT infrastructure. *Journal of Cloud Computing,* **13**(1), pp. 59.

[10] BANERJEE, A. and R, R.N., 2022. A comprehensive overview on BIM-integrated cyber physical system architectures and practices in the architecture, engineering and construction industry. *Construction Innovation,* **22**(4), pp. 727-748.

[11] BILENKO, P., ARTAMONOVA, I., KOLESNICHENKO, A. and OSIPOV, D., 2020. Evaluation of investment efficiency in cyber-physical systems and technologies in the construction industry. *IOP Conference Series.Materials Science and Engineering,* **869**(6),.

[12] CALABRÒ, A., CAMBIASO, E., CHEMINOD, M., BERTOLOTTI, I.C., DURANTE, L., FORESTIERO, A., LOMBARDI, F., MANCO, G., MARCHETTI, E., ORLANDO, A. and PAPUZZO, G., 2024. A Methodological Approach to Securing Cyber-Physical Systems for Critical Infrastructures. *Future Internet,* **16**(11), pp. 418.

[13] CHEN, Y., BANERJEE, S., DAILY, S., KROLIK, J., LI, H.H., LIMBRICK, D., PAJIC, M., RUNTON, R. and ZHONG, L., 2024. Athena - The NSF AI Institute for Edge Computing. *AI Magazine,* **45**(1), pp. 15-21.

[14] DEHGHAN, S., SASAN, S.K., ECHCHAKOUI, S. and BARKA, N., 2025. The Integration of Additive Manufacturing into Industry 4.0 and Industry 5.0: A Bibliometric Analysis (Trends, Opportunities, and Challenges). *Machines,* **13**(1), pp. 62.

[15] DESHKAR, P.A., DESHMUKH, M.S., PURI, N., PATIL, A.R.B., THAKARE, A. and DAHIGAONKAR, D.J., 2024. Modeling Nonlinear Physical Systems in a Real-Time Operating System Environment for Control and Cyber Threat Mitigation. *Journal of Electrical Systems,* **20**(3), pp. 1996-2003.

[16] DING, S., LU, S., XU, Y., KORKALI, M. and CAO, Y., 2023. Review of cybersecurity for integrated energy systems with integration of cyber-physical systems. *Energy Conversion and Economics,* **4**(5), pp. 334-345.

[17] DINIZ, F.F., GADELHA, A.A.B., DE SOUZA, J.,CARNEIRO MARTINS, FILHO, R.D.S.R., SANTOS, J.J.D.N., GADELHA, P.M.B., DE MELO, M.C. and MONTEIRO, V.E.D., 2024. SUSTAINABILITY IN INDUSTRY 4.0: A SYSTEMATIC REVIEW. *Revista de Gestão Social e Ambiental,* **18**(2), pp. 1-12.

[18] EUSEBIO JIMÉNEZ LÓPEZ, LIMON LEYVA, P.A., ARMANDO AMBROSIO LÓPEZ, OCHOA ESTRELLA, F.J., JUAN JOSÉ DELFÍN VÁZQUEZ, BALDOMERO LUCERO VELÁZQUEZ and MARTÍNEZ MOLINA, V.M., 2024. Mechanics 4.0 and Mechanical Engineering Education. *Machines,* **12**(5), pp. 320.

[19] FETT, M., WILKING, F., GOETZ, S., KIRCHNER, E. and WARTZACK, S., 2023. A Literature Review on the Development and Creation of Digital Twins, Cyber-Physical Systems, and Product-Service Systems. *Sensors,* **23**(24), pp. 9786.

[20] GALLAB, M., DI NARDO, M. and NACIRI, L., 2024. Navigating contemporary challenges and future prospects in digital industry evolution. *SN Applied Sciences,* **6**(5), pp. 259.

[21] GONZALEZ-MARTINEZ, G., SANDOVAL-ARECHIGA, R., LUIS OCTAVIO SOLIS-SANCHEZ, GARCIA-LUCIANO, L., IBARRA-DELGADO, S., JUAN RAMON SOLIS-ESCOBEDO, GOMEZ-

RODRIGUEZ, J. and RODRIGUEZ-ABDALA, V., 2024. A Survey of MPSoC Management toward Self-Awareness. *Micromachines,* **15**(5), pp. 577.

[22] GUHA, B., MOORE, S. and HUYGHE, J.M., 2023. Conceptualizing data-driven closed loop production systems for lean manufacturing of complex biomedical devices—a cyber-physical system approach. *Journal of Engineering and Applied Science,* **70**(1), pp. 50.

[23] HAMZAH, M., MD, M.I., HASSAN, S., MD, N.A., MOST, J.F., MUHAMMED, B.J. and ALI, W.M., 2023. Distributed Control of Cyber Physical System on Various Domains: A Critical Review. *Systems,* **11**(4), pp. 208.

[24] HOZDIĆ, E. and MAKOVEC, I., 2023. Evolution of the Human Role in Manufacturing Systems: On the Route from Digitalization and Cybernation to Cognitization. *Applied System Innovation,* **6**(2), pp. 49.

[25] JIANG, Y., WANG, W., DING, J., LU, X. and JING, Y., 2024. Leveraging Digital Twin Technology for Enhanced Cybersecurity in Cyber–Physical Production Systems. *Future Internet,* **16**(4), pp. 134.

[26] KUMAR, K.J.J., MANIKANTHAN, S.V., RAMADAS, G., BHUPATI and GIRI, R.K., 2024. Robotic and Autonomous Systems (RAS): Dynamic Modeling of Cyber-physical Environments. *Journal of Electrical Systems,* **20**(4), pp. 2331-2340.

[27] MAYER, A., GREIF, L., TIM MARKUS HÄUßERMANN, OTTO, S., KASTNER, K., BOBBOU, S.E., JEAN-RÉMY CHARDONNET, REICHWALD, J., FLEISCHER, J. and OVTCHAROVA, J., 2025. Digital Twins, Extended Reality, and Artificial Intelligence in Manufacturing Reconfiguration: A Systematic Literature Review. *Sustainability,* **17**(5), pp. 2318.

[28] MENDONCA, R.S., MARIÉLIO, D.S., AYRESJR, F.A.C., BESSA, I.V., MEDEIROS, R.L.P. and LUCENAJR, V.F., 2025. Development of a Novel Retrofit Framework Considering Industry 4.0 Concepts: A Case Study of a Modular Production System. *Processes,* **13**(1), pp. 136.

[29] MOHAMMAD, A.A., MOHAMMED NASSER AL-ANDOLI, GHALEB, M., THABIT, R., ALKAWSI, G., JAMIL ABEDALRAHIM, J.A. and GAID, A.S.A., 2025. Security of Smart Grid: Cybersecurity Issues, Potential Cyberattacks, Major Incidents, and Future Directions. *Energies,* **18**(1), pp. 141.

[30] NICHOLAS, J., TAN, Q. and VILLAR, J.R., 2023. A Review of Anomaly Detection Strategies to Detect Threats to Cyber-Physical Systems. *Electronics,* **12**(15), pp. 3283.