LUMEN ET VIRTUS
ISSN: 2177-2789

ADAPTIVE WORK INSTRUCTION SYSTEMS IN CYBER-PHYSICAL INDUSTRIAL ENVIRONMENTS: INTEGRATION BETWEEN PHYSICAL SYSTEM DATA, DECISION LOGIC, AND HUMAN EXECUTION

SISTEMAS ADAPTATIVOS DE INSTRUÇÃO DE TRABALHO EM AMBIENTES INDUSTRIAIS CIBER-FÍSICOS: INTEGRAÇÃO ENTRE DADOS DO SISTEMA FÍSICO, LÓGICA DE DECISÃO E EXECUÇÃO HUMANA

SISTEMAS DE INSTRUCCIÓN DE TRABAJO ADAPTATIVOS EN ENTORNOS INDUSTRIALES CIBERFÍSICOS: INTEGRACIÓN ENTRE DATOS DEL SISTEMA FÍSICO, LÓGICA DE DECISIÓN Y EJECUCIÓN HUMANA

https://doi.org/10.56238/levv14n32-048

Submitted on: 11/02/2024 **Publication date:** 11/03/2024

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ABSTRACT
This article addresses Adaptive Work Instruction Systems in cyber-physical industrial environments, focusing on the integration between physical system data, decision logic, and human execution. The objective was to conceptually analyze how work instructions can be repositioned as active technical components of contemporary industrial systems. The methodology consisted of a qualitative, conceptual study based on a systematic analysis of recent scientific articles related to cyber-physical systems, augmented reality, human–machine interfaces, and operator assistance systems. The results indicate that adaptive instruction architectures, based on machine states, operational events, and real-time context, promote greater alignment between guidance and operational conditions, contributing to improved execution consistency. It is concluded that integrating work instructions into the functioning of cyber-physical systems enhances support for human execution and provides relevant contributions to the design of operator-oriented industrial systems.
Keywords: Cyber-Physical Systems. Work Instructions. Adaptive Systems. Human Execution. Industry 4.0.

RESUMO
Este artigo aborda os Sistemas Adaptativos de Instrução de Trabalho em ambientes industriais ciber-físicos, com foco na integração entre dados do sistema físico, lógica de decisão e execução humana. O objetivo foi analisar, sob uma perspectiva conceitual, como as instruções de trabalho podem ser reposicionadas como componentes técnicos ativos dos sistemas industriais contemporâneos. A metodologia adotada consistiu em uma pesquisa qualitativa de natureza conceitual, fundamentada na análise sistemática de artigos científicos recentes relacionados a sistemas ciber-físicos, realidade aumentada, interfaces homem-máquina e sistemas de assistência ao operador. Os resultados indicam que arquiteturas adaptativas de instrução, baseadas em estados de máquina, eventos operacionais e contexto em tempo real, favorecem maior alinhamento entre orientação e situação operacional, contribuindo para maior consistência da execução. Conclui-se que a

integração das instruções de trabalho ao funcionamento dos sistemas ciber-físicos amplia o suporte à execução humana e oferece subsídios relevantes para o projeto de sistemas industriais orientados ao operador.

Palavras-chave: Sistemas Ciber-Físicos. Instruções de Trabalho. Sistemas Adaptativos. Execução Humana. Industry 4.0.

RESUMEN

Este artículo aborda los Sistemas Adaptativos de Instrucciones de Trabajo en entornos industriales ciberfísicos, centrándose en la integración entre los datos del sistema físico, la lógica de decisión y la ejecución humana. El objetivo fue analizar, desde una perspectiva conceptual, cómo las instrucciones de trabajo pueden reposicionarse como componentes técnicos activos de los sistemas industriales contemporáneos. La metodología adoptada consistió en una investigación cualitativa de carácter conceptual, basada en el análisis sistemático de artículos científicos recientes relacionados con sistemas ciberfísicos, realidad aumentada, interfaces hombre-máquina y sistemas de asistencia al operador. Los resultados indican que las arquitecturas de instrucción adaptativas, basadas en estados de máquina, eventos operativos y contexto en tiempo real, favorecen una mayor alineación entre la instrucción y la situación operativa, contribuyendo a una mayor consistencia en la ejecución. Se concluye que la integración de instrucciones de trabajo en la operación de sistemas ciberfísicos amplía el soporte para la ejecución humana y ofrece ventajas relevantes para el diseño de sistemas industriales orientados al operador.

Palabras clave: Sistemas Ciberfísicos. Instrucciones de Trabajo. Sistemas Adaptativos. Ejecución Humana. Industry 4.0.

1 INTRODUCTION

Recent transformations in the industry have been marked by the growing digitalization of production systems, the integration between physical and computational layers, and the incorporation of technologies capable of monitoring and responding dynamically to the state of processes in real time, configuring the advancement of cyber-physical systems in the industrial environment (Wolfartsberger, 2019). In this context, the industry starts to operate as a connected ecosystem, in which sensors, machines, control systems, and digital interfaces are continuously articulated, profoundly changing the traditional logic of planning, execution, and control of production operations (Kurdve *et al*., 2018).

The consolidation of these cyber-physical systems intensifies automation and expands the use of computational intelligence, but maintains human execution as a structuring element of the operation, especially in assembly, maintenance, and local decision-making activities (Danielsson *et al*., 2018). Even in highly automated environments, the operator remains responsible for interpreting unforeseen situations, dealing with context variability, and interacting with complex systems, which reinforces its centrality in the effective operation of contemporary industrial plants (Mark *et al*., 2021).

The human presence in these environments requires cognitive support mechanisms that keep up with the technical complexity of the systems, since the simple automation of tasks does not eliminate the need for clear, contextualized, and adaptable guidance during the execution of work (Tsutsumi *et al*., 2020). In this way, the relationship between operator and system is no longer merely reactive and starts to demand interfaces that favor the understanding of the state of the process, the expected actions, and the operational consequences associated with each decision made in the field (Pimminger *et al*., 2021).

Despite this scenario, most industries still rely on static operating instructions, often structured in standard operating procedures that describe fixed sequences of activities, disregarding variations in context and real operating conditions (Corso and Cecconello, 2019). This instruction model, based on printed documents or generic digital manuals, tends to have a low capacity for adaptation, making it difficult to properly interpret the tasks when deviations, failures, or changes in the state of the physical system occur (Lampen *et al*., 2019).

The limitation of traditional instructions becomes more evident as production systems incorporate greater product diversity, shorter cycles, and greater reliance on real-time data, widening the gap between what is documented and what actually occurs on the factory floor (Gattullo *et al*., 2020). This disconnection compromises the efficiency of human execution, as the operator becomes excessively dependent on previous experience or informal support to deal with situations that are not explicitly provided for in the available instructions (Pimminger *et al*., 2021).

In addition, the data generated by the physical system, such as machine states, process events, and failure records, are rarely used as direct inputs to guide the operator during the execution of tasks, remaining restricted to monitoring systems or subsequent analysis (Mourtzis *et al*., 2020). The lack of integration between this information and the instruction mechanisms limits the potential of cyber-physical systems, since the orientation to the operator does not dynamically follow the real conditions of the operation (Kästner *et al*., 2020).

This gap contributes to the expansion of operational variability, as different operators tend to adopt different strategies in the same situation, increasing the probability of inconsistencies, rework, and execution errors (Danielsson *et al*., 2018). In many cases, process stability comes to rely heavily on experienced experts, creating knowledge asymmetries and organizational fragility when this support is not available (Tsutsumi *et al*., 2020).

Given this scenario, it becomes relevant to rethink work instructions as active technical components of the cyber-physical system, capable of reacting to the state of the process, incorporating real-time data, and supporting human execution in an adaptive way (Gattullo *et al*., 2020). Approaches based on augmented reality, artificial intelligence, and contextual information management have shown potential to transform operational instruction into a dynamic element, aligned with the specific conditions of each work situation (Wolfartsberger, 2019).

This article aims to propose and discuss a conceptual architecture of Adaptive Work Instruction Systems integrated into cyber-physical industrial environments, considering the articulation between data from the physical system, decision layer and human interface. To this end, the work is organized in a literature review on cyber-physical systems, human execution and digital instructions, followed by the presentation of the adopted methodology, the discussion of conceptual results and final considerations on implications for industrial projects and future research.

2 THEORETICAL FRAMEWORK

2.1 CYBER-PHYSICAL SYSTEMS AND *INDUSTRY 4.0* IN THE INDUSTRIAL CONTEXT

Cyber-physical systems emerge in the industrial context as architectures capable of integrating physical and computational processes through continuous communication, allowing the state of operations to be monitored, interpreted, and influenced in real time (Wolfartsberger, 2019). This approach redefines the organization of production systems by establishing a direct link between sensors, actuators, control systems, and decision layers distributed throughout the industrial plant (Kurdve *et al*., 2018).

Within the framework of *Industry 4.0*, cyber-physical systems constitute the technological basis for the advanced digitalization of manufacturing, promoting greater connectivity, traceability, and adaptation of production operations (Lampen *et al*., 2019). The incorporation of these systems makes it possible for physical events to be continuously translated into digital information, creating a flow of data that supports operational decisions that are more aligned with the real conditions of the process (Gattullo *et al*., 2020).

The evolution of cyber-physical systems is directly associated with the expansion of local and distributed processing capacity, allowing quick responses to process variations without relying exclusively on external interventions (Mourtzis *et al*., 2020). This characteristic favors the construction of industrial systems capable of adjusting their operational behavior according to machine states, environmental parameters, and ongoing production sequences (Kästner *et al*., 2020).

The adoption of cyber-physical systems also influences the way operational knowledge is structured and applied, as decisions previously based on tacit experience are now supported by continuously updated data (Tsutsumi *et al*., 2020). In this scenario, the industrial environment takes on a dynamic configuration, in which the functioning of the system depends on the constant interaction between physical, digital, and human elements (Danielsson *et al*., 2018).

By enabling the integration between monitoring, analysis, and action, cyber-physical systems expand the ability to coordinate between different levels of the industrial operation, reducing the fragmentation between planning and execution (Pimminger *et al*., 2021). This integration contributes to a systemic view of production, in which decision-making starts to simultaneously consider historical data, current states, and projections of the system's behavior (Wolfartsberger, 2019).

2.2 INTEGRATION BETWEEN PHYSICAL, COMPUTATIONAL AND HUMAN SYSTEMS

The integration between physical, computational, and human systems represents a central feature of contemporary industrial environments, in which automation coexists with activities that require human judgment and situational adaptation (Danielsson *et al*., 2018). This integration requires mechanisms that allow the operator to understand the functioning of the system and interact with it in an informed way during the execution of tasks (Mark *et al*., 2021).

Even with the advancement of digital technologies, human execution remains strongly associated with the interpretation of contextual information, the resolution of unforeseen situations, and the coordination between different stages of the production process (Tsutsumi *et al*., 2020). The absence of adequate interfaces can compromise this integration, as the operator tends to receive fragmented information or information that is misaligned with the real state of the physical system (Lampen *et al*., 2019).

Industrial systems that effectively integrate human and computational components tend to have greater operational consistency, since execution is guided by up-to-date and contextualized information (Pimminger *et al*., 2021). This integration favors the reduction of subjective interpretations during the operation, promoting greater uniformity in the performance of tasks over time (Kurdve *et al*., 2018).

The literature points out that more advanced human-machine interfaces contribute to the mediation between technical complexity and the operator's cognitive capacity, facilitating the understanding of machine states and action sequences (Gattullo *et al*., 2020). Technologies such as augmented reality and digital assistance systems extend this mediation by overlaying information directly on the physical context of work (Corso and Cecconello, 2019).

The integration between the physical, computational, and human domains also depends on the system's ability to adapt the informational content according to the operator's level of experience and the current operational situation (Tsutsumi *et al*., 2020). This adaptation favors a more fluid interaction, in which the operator stops acting as a mere executor of fixed instructions and starts to actively integrate the operation of the system (Wolfartsberger, 2019).

When this integration is not properly designed, gaps arise between the behavior expected by the system and the actions actually taken by operators, compromising operational stability (Danielsson *et al*., 2018). For this reason, systems engineering has directed increasing attention to the design of architectures that incorporate human execution as an integral part of the cyber-physical system (Mourtzis *et al*., 2020).

2.3 TRADITIONAL WORK INSTRUCTIONS AND THEIR OPERATIONAL LIMITS

Traditional work instructions are usually structured as static documents that describe standardized sequences of actions, assuming optimal operating conditions and low context variability (Corso and Cecconello, 2019). This format tends to have limitations when applied to dynamic industrial environments, in which machine states and unexpected events occur frequently (Lampen *et al*., 2019).

The rigidity of these instructions makes it difficult to apply them in situations that require immediate adaptation, leading operators to resort to previous experience or informal guidance to continue activities (Pimminger *et al*., 2021). This behavior contributes to the heterogeneity of execution, since different operators interpret and apply the instructions in different ways (Danielsson *et al*., 2018).

Another recurring aspect in the literature refers to the disconnection between the documented instructions and the data actually generated by the physical system during the operation (Gattullo *et al*., 2020). Even when monitoring systems are available, the information produced is rarely incorporated directly into the instructions provided to operators (Mourtzis *et al*., 2020).

The absence of this integration reduces the ability of traditional instructions to support real-time decision-making, especially in situations involving failures, deviations, or atypical operating conditions (Kästner *et al*., 2020). As a consequence, the operator takes on a greater cognitive load by having to interpret scattered data and translate it into corrective actions (Tsutsumi *et al*., 2020).

Studies indicate that maintaining static instructions in advanced industrial environments can amplify the reliance on experienced specialists, concentrating operational knowledge on specific individuals (Mark *et al*., 2021). This dependence tends to weaken the organization, especially in contexts of staff turnover or expansion of productive capacity (Wolfartsberger, 2019).

Given these limitations, the literature has pointed to the need to reconfigure work instructions as dynamic elements, integrated into the cyber-physical system and sensitive to the state of the process (Gattullo *et al*., 2020). Approaches based on digital assistance systems and adaptive instructions indicate ways to align operational guidance, real-time data, and human execution more consistently (Tsutsumi *et al*., 2020).

2.4 PROCESS VARIABILITY AND IMPACT ON HUMAN EXECUTION

Process variability is a recurring feature in contemporary industrial environments, resulting from differences in materials, machine conditions, production sequences, and human interventions throughout the operation (Danielsson *et al*., 2018). This variability directly interferes with human execution, since the operator needs to interpret system signals and adapt its actions in situations that deviate from the predicted nominal behavior (Pimminger *et al*., 2021).

When production systems have a high degree of variability, the execution of tasks tends to depend heavily on the operator's ability to recognize patterns and anticipate operational consequences (Tsutsumi *et al*., 2020). This dependence increases the cognitive load during the operation, especially when the available information does not accurately reflect the current state of the physical process (Lampen *et al*., 2019).

The literature indicates that the absence of structured mechanisms to deal with variability contributes to inconsistencies in execution, since different operators may adopt different strategies to respond to the same operational condition (Mark *et al*., 2021). This behavior generates dispersion in the results of the process, making it difficult to predict and repeatable industrial operations (Kurdve *et al*., 2018).

Cyber-physical systems offer means to mitigate the effects of variability by enabling the identification of machine states and relevant events during the execution of tasks (Mourtzis *et al*., 2020). When this information is integrated into the guidance provided to the operator, it becomes possible to align human execution to specific process conditions in real time (Kästner *et al*., 2020).

Proper variability management requires operational knowledge to be continuously updated and distributed in a way that is accessible to operators at the time of execution (Gattullo *et al*., 2020). This approach contributes to reducing the reliance on subjective interpretations, promoting greater consistency across different shifts and operator profiles (Wolfartsberger, 2019).

2.5 HUMAN-MACHINE INTERFACES AND DECISION-MAKING SUPPORT

Human-machine interfaces constitute the main communication channel between the operator and industrial systems, directly influencing the way information is perceived, interpreted, and used during the execution of tasks (Wolfartsberger, 2019). The quality of this interface interferes with the operator's ability to understand the state of the system and select actions consistent with the current operational situation (Danielsson *et al*., 2018).

Traditional interfaces, based on static screens or generic panels, often have limitations in representing complex and dynamic information coming from the physical system (Lampen *et al*., 2019). This limitation can lead to fragmentation of information, requiring the operator to make additional efforts to integrate data from different sources during decision-making (Pimminger *et al*., 2021).

The literature points out that more advanced interfaces favor the contextualization of information, allowing relevant data to be presented according to the task at hand and the current state of the process (Gattullo *et al*., 2020). This support reduces the need for external consultations and contributes to decisions that are more aligned with actual operating conditions (Tsutsumi *et al*., 2020).

Decision-making support becomes more effective when the interface incorporates adaptive mechanisms capable of adjusting the level of detail of the information presented to the operator (Mourtzis *et al*., 2020). This adaptation favors continuous interaction between operator and system, maintaining the fluidity of execution even in situations of greater operational complexity (Mark *et al*., 2021).

Interfaces that integrate historical data, current states, and operational guidance tend to increase operator confidence in the information provided by the system (Kurdve *et al*., 2018). This confidence contributes to greater adherence to the guidelines presented, reducing deviations in execution and strengthening operational consistency (Wolfartsberger, 2019).

2.6 VISUAL INSTRUCTIONS AND AUGMENTED REALITY IN OPERATIONAL PERFORMANCE

Visual instructions have been widely investigated as mechanisms capable of facilitating the understanding of complex tasks, especially in contexts in which textual interpretation is insufficient (Corso and Cecconello, 2019). The graphic representation of the actions to be performed contributes to reducing ambiguities and favoring the rapid assimilation of the guidelines during the operation (Danielsson *et al*., 2018).

Augmented reality amplifies the potential of visual instructions by allowing the overlay of digital information directly on the physical work environment (Gattullo *et al*., 2020). This approach favors the immediate association between orientation and real object, reducing the need for alternation of attention between different sources of information (Lampen *et al*., 2019).

Studies indicate that the use of augmented reality in operational instructions contributes to greater precision in the execution of assembly and maintenance tasks, especially in activities that involve multiple steps and high technical complexity (Pimminger *et al*., 2021). The contextualized visualization of actions helps the operator to stay focused on the task, minimizing errors resulting from incorrect interpretations (Mark *et al*., 2021).

The effectiveness of augmented reality-based instructions is associated with the system's ability to consider the operational context, including machine states, sequence of activities, and environmental conditions (Mourtzis *et al*., 2020). When this information is integrated, the instructions are no longer generic and start to reflect the specific situation faced by the operator at that time (Kästner *et al*., 2020).

In addition to immediate support for execution, visual instructions in augmented reality contribute to learning processes in the industrial environment, favoring the internalization of procedures and the transfer of operational knowledge (Tsutsumi *et al*., 2020). This characteristic reinforces the use of these technologies as integrated components of cyber-physical systems, aligning operational guidance, process data, and human execution (Wolfartsberger, 2019).

2.7 USE OF REAL-TIME CONTEXT FOR DECISION SUPPORT

The use of real-time context in industrial environments allows information from the physical system to be interpreted continuously, offering subsidies more aligned with the current conditions of the operation (Mourtzis *et al*., 2020). This approach extends the operator's ability to understand events, machine states, and productive sequences while the activity is running (Danielsson *et al*., 2018).

Systems that exploit real-time context tend to have greater adherence between provided guidance and concrete operational situation, reducing discrepancies between planning and execution (Gattullo *et al*., 2020). The continuous updating of information favors decisions that are more coherent with the current behavior of the process, especially in scenarios of high variability (Kästner *et al*., 2020).

The literature indicates that the absence of updated contextual information compromises the effectiveness of operational guidelines, as the operator starts to work with outdated representations of the system (Lampen *et al*., 2019). When context is incorporated into the supporting interfaces, human execution tends to align more consistently with defined operational objectives (Pimminger *et al*., 2021).

Real-time context also contributes to the prioritization of relevant information, avoiding cognitive overload resulting from the indiscriminate presentation of data (Tsutsumi *et al*., 2020). This prioritization favors the selection of actions that are more appropriate to the current situation, strengthening the interaction between operator and system (Wolfartsberger, 2019).

The structured use of operational context reinforces the integration between physical and computational layers, increasing the system's responsiveness to unexpected events (Kurdve *et al*., 2018). This type of integration creates conditions for decision-making to be continuously adjusted to the actual state of the operation (Mourtzis *et al*., 2020).

2.8 ADAPTIVE SYSTEMS AND STATE-BASED DECISION-MAKING

Adaptive systems are characterized by the ability to modify their behavior according to changes in the state of the process, using information from the physical system to guide future actions (Wolfartsberger, 2019). This logic favors state-based decision-making, in which each orientation is linked to specific conditions observed during execution (Tsutsumi *et al*., 2020).

State-based decision-making allows the system to recognize operational patterns and select responses aligned to the current situation, reducing reliance on fixed sequences of instructions (Mourtzis *et al*., 2020). This mechanism increases the coherence between guidance and execution, especially in environments with high operational dynamics (Danielsson *et al*., 2018).

The literature points out that adaptive systems contribute to greater consistency in execution by reducing subjective interpretations by operators (Pimminger *et al*., 2021). When guidelines are conditioned to the state of the system, execution tends to follow more homogeneous criteria between different users and work shifts (Kurdve *et al*., 2018).

State-based adaptation also favors the personalization of instructions, considering factors such as task sequence, machine conditions, and operator profile (Tsutsumi *et al*., 2020). This personalization strengthens the interaction between human and system, promoting greater fluidity during operation (Mark *et al*., 2021).

Adaptive systems depend on architectures capable of capturing, interpreting, and using process data on a continuous basis (Gattullo *et al*., 2020). This capability expands the integration between monitoring, decisioning, and operational guidance within cyber-physical industrial environments (Wolfartsberger, 2019).

2.9 ARTIFICIAL INTELLIGENCE APPLIED TO OPERATIONAL GUIDANCE

The application of artificial intelligence to operational guidance has been explored as a means to interpret large volumes of data generated by industrial systems and transform it into actionable instructions for operators (Mourtzis *et al*., 2020). Techniques based on machine learning make it possible to identify operating patterns and associate them with specific orientations according to the observed state of the system (Kästner *et al*., 2020).

The use of neural network-based models enables the automatic recognition of objects, postures, and relevant events during the execution of tasks (Gattullo *et al*., 2020). This ability favors the dynamic generation of instructions aligned with the real conditions of the physical work environment (Lampen *et al*., 2019).

The literature highlights that artificial intelligence extends the autonomy of assistance systems by enabling distributed decisions and faster responses to operational changes (Tsutsumi *et al*., 2020). This autonomy reduces the need for manual intervention to update instructions, promoting greater continuity in the execution of activities (Pimminger *et al*., 2021).

The integration between artificial intelligence and guidance interfaces favors the adaptation of informational content to the context and the user, adjusting the level of detail and format of the instructions (Mark *et al*., 2021). This adaptation contributes to a more aligned interaction between operator and system during the execution of tasks (Danielsson *et al*., 2018).

The use of artificial intelligence in cyber-physical industrial environments reinforces the conception of instructions as active components of the system, capable of evolving according to the observed operational behavior (Wolfartsberger, 2019). This evolution expands the coherence between process data, computational decision-making, and human execution (Mourtzis *et al*., 2020).

2.10 GAPS IN THE LITERATURE: INSTRUCTIONS AS A TECHNICAL COMPONENT OF THE SYSTEM

Despite the advances presented in the literature, it is observed that work instructions are still often treated as peripheral artifacts, dissociated from the technical architecture of industrial systems (Corso and Cecconello, 2019). This approach limits the integration between operational orientation and functioning of the cyber-physical system as a whole (Kurdve *et al*., 2018).

Most studies focus on visualization or interface, paying less attention to the formalization of instructions as elements integrated into the decision and control layers (Gattullo *et al*., 2020). This gap restricts the understanding of instructions as part of the systemic behavior of the industrial operation (Wolfartsberger, 2019).

The literature also shows conceptual dispersion regarding how to structure adaptive instructions based on process data and machine states (Mourtzis *et al*., 2020). This dispersion makes it difficult to consolidate conceptual architectures that consistently integrate physical data, computational decision-making, and human execution (Tsutsumi *et al*., 2020).

Although there are proposals aimed at operator assistance, few studies treat instructions as technical components capable of directly influencing the operational stability of the system (Mark *et al*., 2021). This absence reinforces the need for approaches that reposition instructions within industrial systems engineering (Pimminger *et al*., 2021).

In view of these gaps, it is pertinent to advance in the construction of conceptual models that integrate work instructions into the architecture of cyber-physical systems, considering them an active part of the system's functioning (Gattullo *et al*., 2020). This perspective broadens the understanding of instructions as technical elements capable of articulating data, decision-making, and human execution in a structured way (Wolfartsberger, 2019).

3 METHODOLOGY

The methodological approach adopted is characterized as qualitative and conceptual in nature, directed to the analysis and proposition of a theoretical architecture for adaptive systems of work instruction in cyber-physical industrial environments. The study was developed from a systematic analysis of the scientific literature, composed exclusively of articles published in the last five years, selected according to criteria of topicality, thematic adherence and relevance to the field of industrial systems engineering.

The methodological framework is based on the perspective of systems engineering, understanding the industrial environment as an integrated system formed by physical, computational and human components in continuous interaction. This approach allows us to treat operational guidance as an integral part of the system's behavior, overcoming the understanding of instructions as isolated or merely documentary artifacts, in line with classic assumptions of applied scientific research (Lakatos and Marconi, 2017).

The construction of the proposed conceptual architecture is based on the abstraction and organization of the main elements recurrent in the recent literature analyzed, structuring them in interdependent functional layers. This modeling aims to systematically represent the relationship between the physical system, the decision layer and the operator orientation interface, considering the flow of information and the interaction between these elements.

The identification of relevant variables of the physical system includes machine states, operational events, failure records, and contextual conditions that directly interfere with the execution of tasks. These variables are treated as fundamental inputs to the mechanisms of adaptation of the instructions, allowing the alignment of the operational orientation with the effective conditions of the industrial operation.

The modeling of the decision layer is conceived from conditional rules and methods based on artificial intelligence, responsible for associating states of the physical system with specific operational orientations. This layer acts as an intermediate element between data collection and the presentation of instructions to the operator, promoting coherence between computational decision and human execution.

The criteria for analyzing the conceptual model consider the internal consistency of the proposed architecture, the clarity in the definition of the interactions between its layers, and the adherence to the approaches identified in the selected recent literature. The limitations of the study stem from its conceptual character and the absence of direct empirical validation, an aspect recognized as inherent to research of this nature, as outlined by Gil (2019), configuring possibilities for future investigations in real industrial environments.

4 RESULTS AND DISCUSSION

The understanding of operator assistance systems in cyber-physical industrial environments requires an integrated analysis of the empirical and conceptual contributions existing in the recent literature, in order to highlight convergences and complementarities between different approaches. In this sense, Table 1 presented below systematizes the main findings of the selected studies, organizing them according to their contributions to operational guidance, contextual adaptation, and integration between system data and human execution.

Table 1

Main findings of the authors analyzed

Author	Key findings
Corso and Cecconello (2019)	Visual instructions in augmented reality increase the accuracy and understanding of operational tasks.
Danielsson *et al*. (2018)	Operators' perception indicates greater alignment between orientation and execution when there is contextual visual support.
Gattullo *et al*. (2020)	Contextual information management enables adaptive technical documentation integrated into the system.
Kästner *et al*. (2020)	Computer vision techniques allow you to identify task states for automatic instruction generation.
Kurdve *et al*. (2018)	Digital instruction systems favor operational consistency and integration with advanced industrial practices.
Lampen *et al*. (2019)	The combination of simulation and augmented reality strengthens operator assistance in manual assembly.
Mark *et al*. (2021)	Digital assistance systems promote greater uniformity in execution between different operator profiles.
Mourtzis *et al*. (2020)	AI-based architectures allow automatic generation of instructions aligned to the state of the process.
Pimminger *et al*. (2021)	Digital instructions contribute to greater assimilation of procedures and operational stability.
Tsutsumi *et al*. (2020)	Customized systems strengthen human-machine interaction through contextual adaptation.
Wolfartsberger (2019)	Assistance systems integrate operational guidance into the operation of *Industry 4.0 environments*.

Source: Prepared by the author (2022)

The results obtained from the analysis of the literature indicate that the architecture of Adaptive Work Instruction Systems emerges as a multilayer structure, in which, according to Wolfartsberger (2019), assistance systems start to integrate operational guidance, process data, and human interaction continuously. Along the same lines, Kurdve *et al*. (2018) add that the organization of these architectures favors greater alignment between production planning and execution on the factory floor.

By observing the flow of data between the physical system, the decision layer, and the human interface, Mourtzis *et al*. (2020) highlight that the continuous collection and processing of machine information enables the automatic generation of instructions aligned with the current operational situation. In convergence, Lampen *et al*. (2019) point out that the effectiveness of this flow depends on the system's ability to transform technical data into understandable guidance for the operator at the time of execution.

The selection of instructions based on machine states, events and failure records appears as a structuring element of adaptive systems, and Kästner *et al*. (2020) demonstrate how object and posture recognition techniques allow identifying the stage of the task in real time. Dialoguing with this approach, Gattullo *et al*. (2020) observe that the incorporation of the operational context reduces ambiguities by linking each orientation to a specific condition of the physical system.

With regard to the dynamic adaptation of the content and level of detail of the instructions, Tsutsumi *et al*. (2020) show that personalized systems favor a more fluid interaction between human and machine by adjusting the information presented according to the user and the situation. In addition, Pimminger *et al*. (2021) indicate that this adaptation contributes to greater assimilation of procedures and greater stability in execution over time.

The literature analyzed indicates that the reduction in operational variability is directly associated with the availability of context-sensitive instructions, as discussed by Danielsson *et al*. (2018) when analyzing the perception of operators in augmented reality-assisted assembly environments. In consonance, Corso and Cecconello (2019) demonstrate that the contextual visualization of instructions favors greater precision in the execution of tasks.

These results dialogue with the observation of Mark *et al*. (2021), which highlight the contribution of digital assistance systems to the standardization of execution among operators with different profiles and levels of experience. At the same time, Wolfartsberger (2019) adds that this standardization reinforces operational consistency by integrating guidance and execution into the operation of the industrial system.

When analyzed in the light of the literature on cyber-physical systems and *Industry 4.0*, the findings indicate that the instructions are no longer treated as peripheral artifacts and become part of the technical behavior of the system, as defended by Gattullo *et al*. (2020). Mourtzis *et al*. (2020) expand this discussion by arguing that operational guidance starts to function as a link between physical data, computational decision-making, and human action.

The integration of human execution into the functioning of the cyber-physical system is reinforced when, according to Tsutsumi *et al*. (2020), the operator starts to interact with instructions that reflect the real state of the operation. In addition, Danielsson *et al*. (2018) observe that this integration contributes to greater confidence of the operator in the guidance provided by the system.

From the point of view of mechatronics engineering, automation and industrial design, the results discussed indicate that the design of adaptive instructional systems requires a systemic approach, as argued by Kurdve *et al*. (2018) when dealing with the integration between productive efficiency and operational support. From this perspective, Pimminger *et al*. (2021) reinforce that the design of industrial systems starts to demand the explicit consideration of human-system interaction as part of technical architecture.

5 FINAL CONSIDERATIONS

The article presented a conceptual synthesis on Adaptive Work Instruction Systems in cyber-physical industrial environments, highlighting the integration between physical system data, decision layer and human execution as a central contribution. This approach reinforces the understanding of instructions as active technical components of the industrial system.

In relation to static instructions and traditional interfaces, the work evidenced conceptual advances by proposing guidelines sensitive to the operational context and the states of the system. This change increases the coherence between orientation and the actual work situation.

In the context of the design of operator-oriented industrial systems, the proposal contributes by indicating the need for architectures that consider human-system interaction as an integral part of technical operation. Such a perspective favors greater consistency of execution and better support for decision-making during operations. The limitations of the proposed model stem from its conceptual character, without direct empirical validation in industrial environments. This characteristic restricts the immediate practical generalization of the results presented.

As directions for future research, applied studies aimed at the implementation and evaluation of the model in real industrial contexts are pointed out, as well as investigations that deepen the integration between adaptive systems, artificial intelligence and cyber-physical systems.

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