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Original Article

A mathematical model to identify companies' adaptation variables to cyber-physical production systems

Um modelo matemático para identificar variáveis de adaptação de empresas a sistemas de produção ciberfísicos

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ABSTRACT

Purpose: With the fourth industrial revolution, it becomes necessary to identify how companies are adapting to the use of technologies aimed at cyber-physical production systems. Therefore, this article aimed to verify how the Textile and Clothing sector is adapting to the use of technologies at PCPS.
Design/methodology/approach: The methodology draws from theoretical definitions, followed by a survey in which 61 medium and large companies from the South of Brazil in the textile and clothing sector participated.
Findings: The results showed that the maturity level was classified as intermediate in the validated textile companies, with opportunities for advances in the implementation of real-time monitoring and other technologies of industry 4.0.
Research limitations/implications: The restriction is that the model was tested in the reality of the Brazilian textile industries located in the state of Santa Catarina.
Originality/value: The originality is to propose a model for using cyber-physical systems as a complement to decision-making in production scheduling with ERP that has finite capacity and thus adding an APS algorithm to assist in monitoring production.

Keywords: Production planning and control; Industry 4.0; Benchmarking; Logistic regression; Survey

RESUMO

Objetivo: Com a quarta revolução industrial, torna-se necessário identificar como as empresas estão se adaptando ao uso de tecnologias voltadas aos sistemas de produção ciberfísicos. Portanto, este artigo teve como objetivo verificar como o setor Têxtil e de Vestuário está se adaptando ao uso de tecnologias voltadas aos PCPS.

Metodologia: A metodologia iniciou com definições teóricas, seguidas de *survey*, na qual 61 empresas de médio e grande porte do Sul do Brazil do setor têxtil e de vestuário participaram. Após, foi desenvolvido um modelo matemático com regressão logística.

Resultados: Os resultados apontaram que o nível de maturidade se classificou como intermediário nas empresas têxteis validadas, com oportunidades para avanços na implementação de monitoramento em tempo real e demais tecnologias da indústria 4.0.

Limitações da pesquisa: A restrição é que o modelo foi testado na realidade das indústrias têxteis brasileiras localizadas em Santa Catarina.

Originalidade/valor: A originalidade está em propor um modelo de utilização de sistemas ciberfísicos como complemento à tomada de decisão na programação da produção com ERP que tenham capacidade finita e assim adicionar um algoritmo APS para auxiliar no monitoramento da produção.

Palavras-chave: Planejamento e controle da produção; Indústria 4.0; Benchmarking; Regressão logística; Levantamento

1 INTRODUCTION

Technological development and international competition have shaped the industry and continue to affect production. Thus, one of the biggest concerns in the textile sector is its complex supply chains that deal with diverse raw materials and operations. Elements such as the product life cycle, production history, traceability of raw materials, logistics data, inventory management, better balance between demand and production, in addition to improving organizational administration are some examples of these concerns.

In this competitive environment, Industry 4.0 has been a strategy to bring together various technologies that contribute to the automation and digitalization of processes, making production models effective. Efficiency also matters, as it seeks to meet customer demand, but this requires a systemic understanding of the company. However, many processes within the textile industry are still carried out manually, being subject to errors and undesirable waste . In this context and based on this computational evolution, attention has turned to the use of Cyber-Physical Systems (CPS).

CPS are made up of two layers, one of operational technology (physical) and a virtual one, based on information technology applications (cyber). This technology that enables the fourth industrial revolution exists both in industry and in people's daily lives with the aim of transforming and monitoring data to form a unified production system, known as Enterprise Resource Planning (ERP), in addition to assisting in decision making for promoting simulations, such as Production Programming and Control tasks.

CPS have also advanced with the use of Artificial Intelligence (AI) techniques, however, this is something that is still little explored, especially in the Brazilian textile and clothing industries. Although it is considered a multidisciplinary area, the works mainly focus on studies of system architecture, information processing, software design, sustainable, intelligent and sensing technologies , as well as in image analysis and neural networks. They can also be used as techniques for testing textile materials and AI can be used to automate processes in various circumstances. Furthermore, a better analysis of the textile thread and high-quality defect detection can be carried out with the application of AI and its technologies in production systems. However, to make these applications possible, it is crucial to understand the extent to which Industry 4.0, particularly cyber-physical systems, has been implemented in companies.

In this context, this article aimed to verify how the textile and clothing sector is adapting to the use of technologies at CPS. To achieve this objective, the mixed methodology was characterized as a data survey supported by a literature review, identifying theoretical elements about CPS. Next, a survey was carried out in large and medium-sized textile and clothing industries in Santa Catarina/Brazil. The definition of the size of companies to be diagnosed by this research is justified by the characteristics of the sector, which is mostly made up of micro and small companies with low technical and managerial quality, which make it difficult to implement practices arising from the industry 4.0.

Data analysis supported by logistic regression , was used to verify whether the company size; the Production Order (PO) issuing system; the use of ERP in planning; the completion of POs; the system used for production scheduling; the way the factory is scheduled; knowledge and use of Radio Frequency Identification (RFID); and opinion on smart factories are predictors of having real-time monitoring of production and product quality. Thus, the result of these data allowed the diagnosis of the maturity level regarding the adoption of PCPS in the 61 companies analyzed in the textile and clothing sector. This model can serve as a benchmark for other sectors that are beginning to implement Industry 4.0.

This article is structured into five sessions. The section 1 introduces the CPS, the section 2 presents the background of the historical evolution of manufacturing systems, such as ERP, Advanced Planning and Scheduling (APS), Manufacturing Execution Systems (MES), RFID, Internet of Things (IOT) and Production Cyber-Physical Systems (PCPS) up to the maturity levels for implementation of cyber-physical systems. Section 3 describes the methodological procedure adopted in this article consisting of a survey. Section 4 is destinated to results and analyzes of the degree of implementation of cyber-physical systems in the textile industry, in addition to comparisons with the theoretical framework. Finally, in section 5 is presented the conclusions of this research and give suggestions for future work, in addition to the appendices with the questionnaire applied and the compilation of data.

2 THEORETICAL BACKGROUND

This section is dedicated to the theoretical concepts that supports the survey questions, starting with 2.1 with the evolution of manufacturing systems, the terms APS, MES, IoT, RFID and their relationships with the ERP system. All of these terms are encompassed by the PCPS. Next, item 2.2 presents the maturity levels for the CPS' evolution of manufacturing management systems. Some theoretical concepts are in the Results Section for the purpose of comparing the literature with was found in the application of the survey in companies in Santa Catarina.

The Production Planning and Control (PCP) is responsible for planning material needs, manufacturing resources, supply chain forecasting and sourcing, and other activities collaboratively. This sector needs to combine manufacturing performance and to be increasingly agile and assertive in its actions. Since the 1960s, ERP has been identified, initially in modules, which help the PCP to carry out its functions. Since then, companies have invested in information systems supported by IT Information and Communication, to manage operations and increase their competitive advantages. Studies on PCP and its relationship with industry 4.0 and its enabling technologies reveal the need for in-depth knowledge of the company and its chain of operations to seek sustainability.

ERPs are important because of their ability to integrate material flow, finances and the information that supports organizational strategies, covering functional areas of a company such as logistics, production, finance, accounting and human resources. Furthermore, the data generated is delivered in a consistent manner, which facilitates the smooth flow of information and common functional practices, thereby improving supply chain performance and reducing product manufacturing cycle times. However, just using ERPs alone was not enough, since they mainly address management-level issues, but are unable to prevent capacity problems from occurring on the factory floor. For example, the generation of production schedules, as they adopt an approach to configuring waiting time and infinite capacity loading, the results of ERPs do not represent the reality found in companies.

Thus, still in the 1990s, to complement ERP, Advanced Planning and Scheduling (APS) were launched, which sought to solve the problem of finite capacity scheduling at the factory floor level for planning based on constraints. Such as problems on the factory floor, such as variable workloads, bottlenecks, high levels of intermediate stocks, machine idleness, late deliveries, which cannot be resolved easily in the short term. APS use complex mathematical algorithms to forecast demand, plan and schedule production within specified constraints, and derive optimal supply and product mix solutions, thus generating a viable production plan Therefore, in recent years, APSs have become decision support tools, when suppliers began to integrate them into existing management systems, such as ERP, complementing them and forming a CPS. indicate ways for APS to become intelligent by seeking the integration of all areas of a company, but for this to happen they must be adapted to their environment and work method, which reveals the importance of knowing the degree of maturity of the company.

CPS allows you to efficiently monitor and share various types of manufacturing information. In this sense, MES-type systems, which are systems that manage factory floor processes and make the connection between production planning and control, can be seen as a CPS for manufacturing. Their principal application focuses on information integration. MES was developed in the 1970s to assist in the execution of production, with the proposal for online management of activities on the factory floor. Beginning in the mid-1990s, MES evolved significantly into powerful, integrated software applications as computing technologies advanced, bringing improvements in factory floor control and operability through real-time data collection and analysis. However, the evolutionary trajectory of the MES had several counterpoints, mainly due to the characteristics and particularities of industries that produce diversified products, such as textiles and clothing.

The MES can be described as the bridge between the integrated planning system and control systems, such as sensors, Programmable Logic Controllers (PLC) and the like, and uses internal manufacturing information, such as equipment, resources and orders to support manufacturing processes. MES arose from the need to deal with progress, resources, maintenance, quality, provenance monitoring and tracking requirements in manufacturing, as it provides decision support for managers. Since monitoring production data is seen as an essential practice for controlling a manufacturing process with a high level of specialization.

In this way, MES does not actually perform manufacturing, that is, the control of equipment and production of goods, but rather manages activities based on the production schedule and the situation on the factory floor through collection, analysis and presentation of data generated in industrial production in real time. The MES, therefore, must be capable of managing various activities such as releasing production orders, executing and controlling production, managing equipment status, linking shop floor supervision, material delivery and consumption management. The aim is to completely avoid the work of issuing production orders on paper, making the factory intelligent.

Therefore, the concept of smart factories, where trends for the future rely on real-time software compatibility, through the Internet of Things (IoT), makes the scope of possibilities for MES expand . However, the adoption of an MES system requires the installation of dedicated hardware, issues that can be quite problematic for small and medium-sized companies in terms of viability, infrastructure and resources available for investment. Thinking about the variety of companies, proposed a reference model, containing eleven types of functions that the MES can perform in order to meet the needs of a variety of manufacturing environments as programming, process management, document control, acquisition data collection, data management, quality management, product dispatch, maintenance management, product tracking, performance analysis and, status and resource allocation.

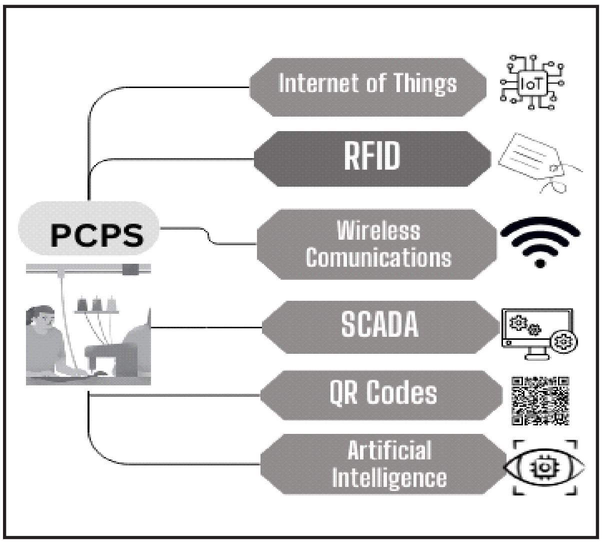
With the introduction of MES in organizations, it was possible to observe greater dynamization of the workflow through data integration, benefits related to the reduction of manufacturing time, improvement of product quality, and rationalization of the practice of predictive maintenance . Furthermore, the MES provides performance analysis in measuring task execution parameters, calculating key performance indicators (KPIs) in quality, availability, productivity and comparing them with the goals established by the organization or external regulatory bodies, as well as how to present and visualize these KPIs to various stakeholders.

However, the variety of manufacturing equipment types hampers shop floor connectivity, and today's industries have difficulty handling manufacturing management activities, mainly due to the lack of infrastructure for data collection, analysis and integration of data manufacturing. This means that there is no way to obtain useful information from the factory floor without adopting technology that transports the data, considering the different sources, formats and various communication interfaces. In this sense, the union between MES and ERP can be essential for the horizontal and vertical integration of systems, the PCP, then, starts to have intelligent capabilities and attributes that link the planning and control of the factory floor and its interface activities.

The analytical structure of an intelligent PCP has modeling based on two agents, orders and resources. The order agent monitors the general schedule, the demand itself, specifies the process route, reserves appropriate resources and performs production control. The resource agent monitors whether the corresponding resource can be operated or not, and through the use of RFID tags in the production order or through feedback from the machines' PLC Programmable Logic Controllers, it indicates whether the worker is operating the machine or not, being able to change an original PCP programming.

RFID technology is used to track and identify items throughout the production and logistics chain. In the textile industry, this allows for more accurate inventory control, reducing errors and improving the efficiency of stock management. Specifically, although there are more modern technologies such as IoT, wireless communication (wi-fi, Zigbee and Bluetooth), computer vision (camera technologies and image processing algorithms to monitor and analyze operations in real time) and SCADA (Supervisory Control and Data Acquisition) systems, in the textile industry, which is considered traditional, RFID predominates. Figure 1 highlights these technologies and their relationship with PCPS, with the focus being on RFID due to the results that will be described from the survey carried out.

Figure 1 – Real-time item tracking and monitoring technologies



Source: the authors

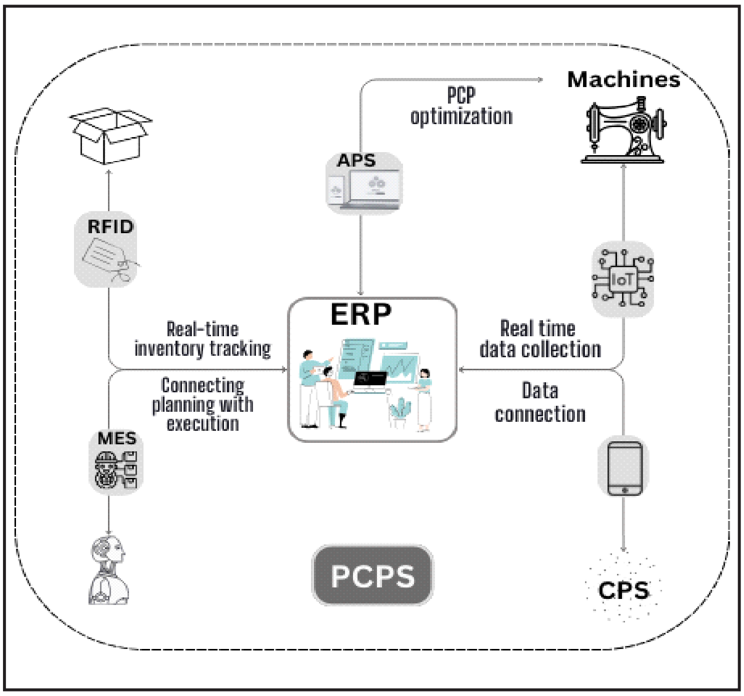
An intelligent Production Cyber-Physical Systems (PCPS), in which at the bottom we find the components of the physical factory, such as machines and discrete sensing devices, which transmit data to the cloud platform, tools, products, materials and people, whose information is provided directly to the platform using MES. Cloud related components are shown on the top right side and these components include the information stored in the database, the web services used for managing the information. The information generated by MES-compatible machines and devices are integral parts of the Shop Floor Digital Twin that can be made available to managers, suppliers or customers, who carry out actions related to the factory . In summary, an intelligent and digital PCP, as part of a central manufacturing system, relies on other Industry 4.0 technologies – internet of things, integration of horizontal and vertical systems, digital twin, big data, cloud computing and cybersecurity.

A digital twin is a virtual replica of a physical object, process or system. It uses real-time data and simulation models to mirror the behavior and state of its physical counterpart. In the context of cyber-physical systems, a digital twin enables integration between the physical and digital worlds, providing a comprehensive and detailed view of the system's operation and performance. This is achieved through constant monitoring, collection and analysis of data from interconnected sensors and devices. With this information, predictions, optimizations and better decision-making can be made.

The execution of production orders takes place on machines equipped with PLCs, which, through the CPSs, create the Digital Twin within the MES, which monitors and indicates the status of the machine in real time. With the interconnection of the MES with the ERP, the information is fed back to the PCP through the cloud, where data relating to the execution of orders and the position of stocks within the factory are made available for consultation. The enormous amount of data is stored in Big Data, enabling future analysis of this information . Added to this, data reliability is another key factor, as many computing systems need to obtain reliable data in real time. For modeling physical processes with mathematical abstractions, data is not confined to a single device, but rather as a confluence of embedded systems or constituent devices.

Figure 2 shows how a PCPS works, in which the PCP continues to be the "brain" through the ERP. With the ERP acting as a central system, IoT sensors installed on the machines collect data in real time while the APS helps to optimize the planning and scheduling of production activities, considering constraints such as machine capacity, material availability and delivery times. The CPS connect the data in real time, in which the information can be managed by cell phone, for example. This connection between the physical and digital world improves machine monitoring, predictive maintenance and rapid response to production problems. Again, the ERP coordinates, integrates and optimizes all processes, ensuring that production is efficient, accurate and aligned with the company's strategic objectives. Next, MES systems are important for automatically controlling production machines and robots, and RFID tags are widely used in logistics for inventory and material control.

Figure 2 – ERP connection in a PCPS



Source: the authors

Table 1 summarizes the relationship between MES and ERP.

Table 1 – MES and ERP relationship

	MES	ERP
Definition	It is a system that manages, monitors and controls operations on the factory floor in real time.	It is an integrated business management system that covers several areas, such as finance, purchasing, sales, human resources and, of course, production.
Main function	Connect planning to execution by monitoring production progress, ensuring compliance with production plans, and optimizing resource utilization.	Provide an unified and comprehensive view of all business operations, facilitating strategic and operational decision-making.
Scope	Execution of manufacturing processes, product tracking and real-time data collection.	It covers high-level business processes and provides a centralized database.
Origin and history	1990s from the creation of the Manufacturing Enterprise Solutions Association International (MESA)	1980s with the evolution of Material Requirements Planning (MRP).
Data integration	Collects detailed data from production operations in real time.	Receive data such as production status, inventory levels and MES resource performance in real time.
Information Flow	Receives production plans from the ERP and executes them on the factory floor.	ERP provides production orders, material planning and demand forecasting for MES.
Continuous Improvement	ERP-MES integration enables continuous analysis and feedback between strategic and operational levels, facilitating the identification of areas for improvement and the implementation of corrective actions.	
Advantages	Alignment of production activities, accurate and up-to-date information.	
Traceability and compliance	MES provides detailed traceability of all manufacturing processes required for compliance with standards and regulations.	The ERP uses this information to ensure that quality and regulatory requirements are met.
Focus	Execution of production operations.	Strategic and integrated vision of business operations.

Source: the authors

APS is an ERP module that was developed in the late 1980s to meet the need for more advanced and accurate planning and scheduling in manufacturing operations. In this sense, Table 2 relates APS systems to ERP, describing the differences and advantages in decision support and the integrated view of the company's overall operations and production.

Table 2 – APS and ERP relationship

	APS	ERP
Complementarity	APS systems are specialized in advanced production planning and scheduling. They use sophisticated algorithms to optimize resource allocation, scheduling of production activities, and supply chain management.	ERP systems are designed to integrate and automate business processes across an enterprise, including finance, purchasing, sales, human resources, and production. They provide a centralized, comprehensive view of a company's operations.
Data integration	Using ERP data to create optimized production plans, considering capacity constraints, delivery time and available resources.	Provides detailed data on inventory, production orders, stock levels, customer demand, and more.
Process optimization	Improves production efficiency by creating detailed and optimized schedules, reducing waiting times, minimizing in-process inventories and improving resource utilization.	It ensures the integration and efficiency of business processes, facilitating communication and the exchange of information between different departments.
Decision making	Provides simulation and analysis tools that help make more informed tactical and operational decisions based on planning and scheduling scenarios.	It offers a centralized and accessible database for strategic and operational decision-making.
Visibility and Control	Improves production control by providing detailed visibility into operations progress and resource utilization in real time.	Provides visibility into all aspects of business operations, from order entry to delivery of final products.
Advantages of integration	Data synchronization, resource optimization, more assertive decision making.	
Focus	Optimization of production processes.	Broad and integrated vision of all company operations.

With the evolution of systems towards Industry 4.0, IoT, one of the technologies present in CPS, involves the interconnection of smart devices and sensors that collect and transmit data in real time. These devices can monitor several parameters, such as temperature, humidity, movement, energy consumption, among others.

These controls, once again integrated into the ERP, improve systemic management in companies. In the textile sector, this automation of systems also helps in digital transformation to improve quality and productivity. Table 3 lists the criteria and their respective operation in CPS (IoT) and ERP.

Table 3 – IOT and ERP relationship

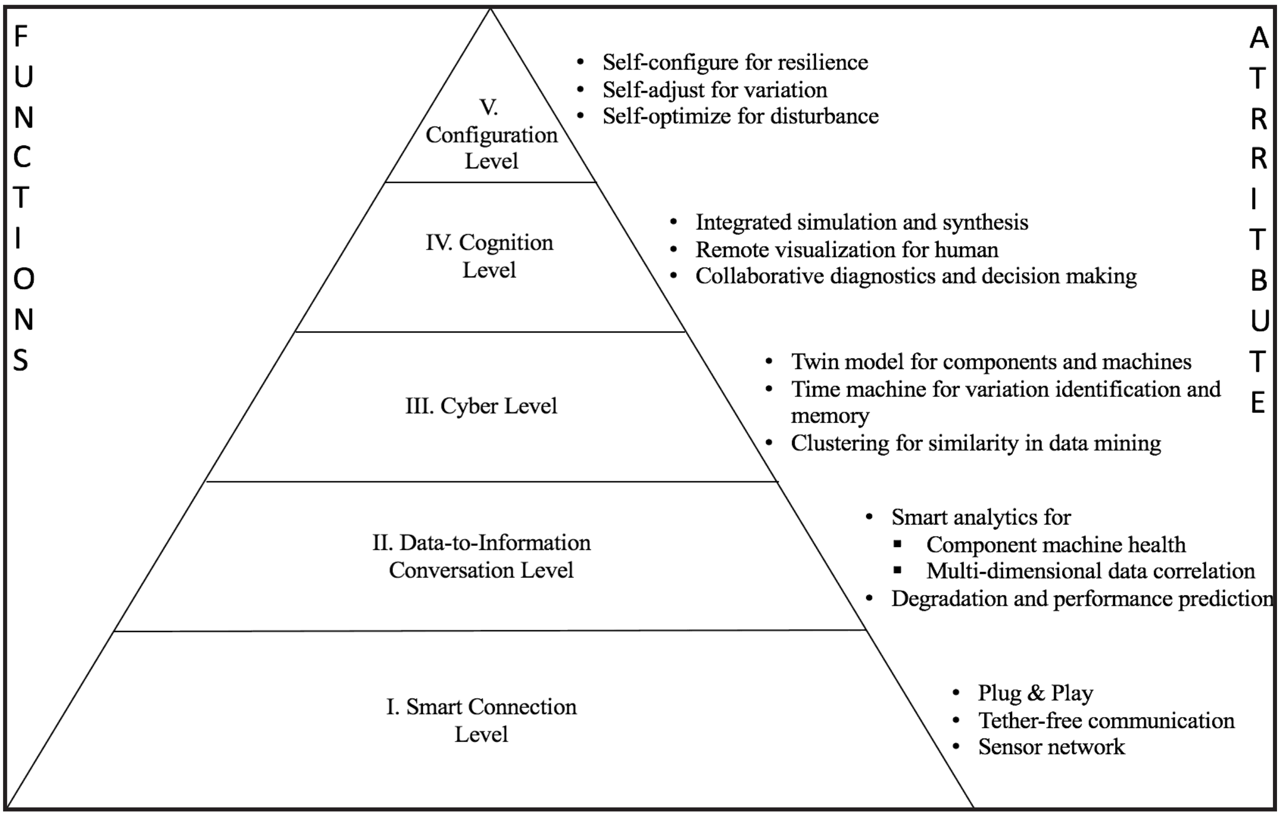
	IoT and CPS	**ERP**
Real-Time Data Collection and Analysis	IoT devices collect real-time data about the health and performance of machines, equipment, processes and products.	Data from IoT sensors is integrated into the ERP system, providing an up-to-date and accurate view of operations. This enables companies to make informed decisions based on real-time, real-world data.
Monitoring and Predictive Maintenance	IoT sensors can monitor the status of machines and equipment, detecting potential failures or problems before they occur.	The ERP system uses this information to schedule predictive maintenance, minimizing downtime and improving operational efficiency.
Optimization of Production Processes	Data collected by IoT sensors allows for detailed analysis of production processes, identifying bottlenecks and opportunities for improvement.	With data from IoT sensors, ERP can automatically adjust production plans, optimize resource allocation, and improve process efficiency.
Inventory and Supply Chain Management	IoT sensors can monitor inventory levels in real time by tracking the location and movement of materials and products.	ERP uses IoT information to maintain accurate inventory control, optimize supply chain management, and avoid overstocks or shortages.
Quality Improvement and Compliance	IoT sensors can monitor critical quality parameters during the production process.	The ERP records and analyzes this data to ensure compliance with quality standards and regulations, facilitating traceability and auditing.
Advantages of integration	Intelligent and connected ecosystem, allowing companies to manage their operations more effectively, accurately and quickly.	

Source: the authors

3 MATURITY LEVELS FOR CPSS

PCP systems have been introduced from traditional models, decision-making support software to combined evolution with CPSs, and the latter also advancing in the context of PCPS. Therefore, this topic is intended to describe CPSs maturity models and their levels so that companies can track implementation progress. emphasize that maturity levels are aimed at different types of cases, and when measured they can identify business opportunities, define which technologies should be adopted, propose improvements for the organization to enter the industry 4.0 era. propose that the application of CPS in manufacturing can be modeled and implemented in a five-level structure, that is, the 5C architecture, as shown in Figure 3. The model to be presented in this article will also classify companies across the five maturity levels.

Figure 3 – 5C architecture for implementing a CPS



Source: Adapted from Kim (2017)

The first level (Figure 3) refers to intelligent connection, on this basis, the acquisition of accurate and reliable data from machines and their components is essential. Data can be measured by sensors or acquired from company controllers or manufacturing systems. The second level is defined as conversational - meaningful information is inferred from data at the data-to-information conversational level. As examples, there are algorithms that were developed specifically for prognosis and health management applications. The third level, in turn, is cybernetic, it functions as the central information hub in this architecture. Information is aggregated and analyzed at this level from each connected machine to form the machine network. Cognition is the fourth level, that is, complete knowledge of the monitored system is generated. Appropriate presentation of acquired knowledge to experienced users helps in decision making. The fifth level, in turn, is configuration, when applying the proposed structure, the 5C architecture for implementing PCPS combines autonomous and cooperative elements and subsystems that are unified at all levels of production .

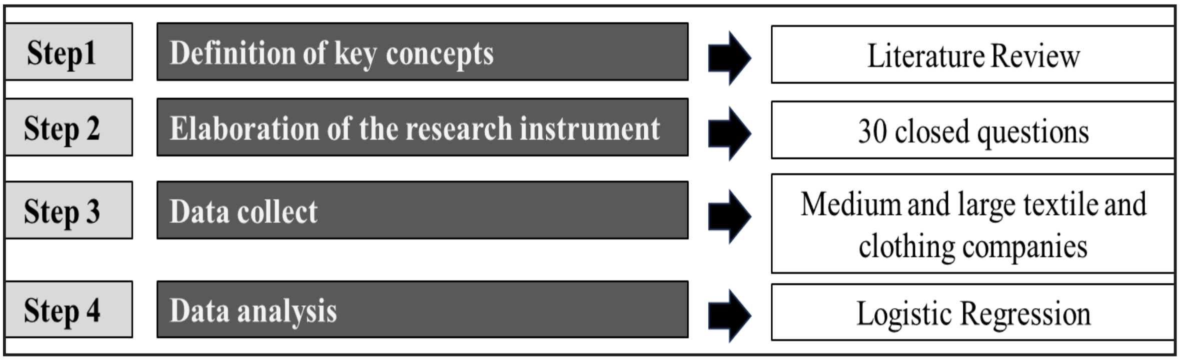
Based on the 5C architecture, suggests a model with five elements to measure maturity in terms of implementation, as shown in Figure 3. Thus, the first level refers to defining basic notions, following which they propose create transparency, increase understanding, improve decision making and, ultimately, self-optimize. While the organizational and structural conditions for the implementation of CPS are created within the first level, the four higher levels represent the maturity of achievements relating to information and knowledge processing and aspects of cooperation and collaboration. The maturity level of the CPS increases with efforts to improve understanding, accumulate data and improve decision making. Understanding the physical world is essential to the implementation and application of a CPS, and a cyber world can be effective if it is built on this understanding .

Thus, the evidence indicates that CPS at the production level will dominate manufacturing systems as a new generation of industry. Furthermore, the adaptation of CPSs to the PCP involves humans, machines and products and combines computing, networking and physical processes in the production process, with the aim of making production more economical and efficient, delivering highly qualified products. The computers and networks embedded in the production CPS serve as the headquarters for monitoring and controlling the physical processes, feedback loops, and performance evaluations in the production process.

4 METHODOLOGY

Scientific methodology can be conceptualized as a set of parameters through which all scientific research is made possible in an organized and judicious manner, thus allowing solutions to be found for the problems raised, in this case, the application of Cyber-Physical Production Systems (CPPS) in Textile and Clothing industry of industry 4.0 . The sequence of methodological steps taken in this work is presented in Figure 4.

Figure 4 – Methodologic Flux



Source: by the authors

Stage 1 included understanding the concepts covered in this document, as well as supporting the construction of the data collection and analysis instrument. To this end, a literature review was carried out on the evolution of management systems and the levels of maturity for implementing CPSs in industries. The final objective of the review was to build an instrument capable of measuring the current scenario of Textile and Clothing industries that seek to adapt to the reality of Industry 4.0 through the introduction of Cyber-Physical Systems.

The development of the research instrument, Stage 2, was carried out through a survey, composed of closed and qualitative questions. A survey is characterized by qualitative research as the search for a deeper understanding by the researcher about a social group, organization or fact, among other perspectives . The questionnaire, then, consisted of 30 closed and multiple-choice questions. The instrument was divided into eight sections, which are free to be completed according to the answers from the previous block. The questions were developed based on the maturity levels presented in section 2.2, identifying which technologies companies currently use it and, based on the result, verifying how the Textile and Clothing sector is adapting to the use of technologies aimed at Cyber-Physical Systems (CPSs), Table 4 presents a summary of the questions and Appendix A in its entirety.

Table 4 – Summary of questions

(Continued)

Nº	Definition of questions	Questions Objective	References
1	Company informational data	Informational data	-
2	Use of ERP to plan the availability of raw materials and intermediate stocks or manufacturing capacity planning;	Check whether the company has an ERP and how it is used, whether continuous or intermittent;	
3	Format for issuing production orders and their destination;	Identify the means of issuing orders, whether on paper, scanned, automatically or otherwise; Check how these orders are discarded, archived, used in reports, notes for the ERP, other manual or automatic system after use;	
4	System used for the PCP;	Check IF the PCP is not computerized, which system is used, Excel, ERP, APS or another system;	Bueno et al. (2020); Hvolby & Steger-Jensen (2010); Jeon et al. (2017); Wang et al. (2021)
5	Production programming logic;	Identify if the production scheduling logic is the same, different in some stages or different in all stages of the process;	Sadiku et al. (2017); Yue et al. (2019)

Table 4 – Summary of questions

(Conclusion)

Nº	Definition of questions	Questions Objective	References
6	Level of knowledge related to cyber-physical production systems (PCPs);	Identify whether managers know the software related to CPSs and, consequently, about industry 4.0, MES, CPS, RFID;	Kim (2017); Mantravadi & Møller (2019); Park et al. (2020); Saenz de Ugarte et al. (2009)
7	Batch tracking via RFID;	Verify whether the evaluated companies had a production batch tracking system using RFID in their internal, outsourced and supplier processes;	Wang et al. (2021); Yue et al. (2019)
8	Company sectors with real-time monitoring;	Check whether the company has and uses real-time monitoring; Identify the characteristics of these systems, such as remote programming, interconnection with the ERP, representation by digital Twin.	Jeon et al. (2017); Saenz de Ugarte et al. (2009); Urbina Coronado et al. (2018); Witsch & Vogel-Heuser (2012)

Source: by the authors

The questions exposed in Table 4 also helped to define the variables that will compose the mathematical model, namely: Company size, Use of an integrated management system, Form of issuing production orders, Finalization of production orders, System used to production scheduling, Process Programming Method, Knowledge about the use of radio frequency, Radio frequency batch tracking, Opinion about smart factories, Function of the online monitoring system.

Stage 3 included data collection, the sample was non-probabilistic, therefore, the choice of elements was directed to planning managers or manufacturing management in Textile and Clothing industries in Santa Catarina, southern Brazil. This type of sample is recommended when researchers do not intend to generalize the results to a population, but to analyze a specific phenomenon restricted to a portion of the population. Furthermore, as observed in the literature, specifically with regard to the implementation of industry 4.0 technologies, the questionnaire was aimed at large and medium-sized companies, totaling 117 referrals and, out of these, 61 responses were considered valid, totaling 48% effectiveness. Table 5 presents the universe of companies and their percentiles.

Table 5 – Companies Population

Region	**Big**	**Medium**	**Total Companies**
Big Florianópolis	2	0	2
(North) Santa Catarina	34	3	37
(West) Santa Catarina	3	0	3
(South) Santa Catarina	8	0	8
Itajaí Valley	7	60	67
Total	*54*	*63*	*117*

Source: by the authors

In the Step 4 the data was analysed using Logistic Regression. Logistic regression is used when there is a need to classify two types of objects, which fall into the class of multivariate statistical methods of dependence, where a categorical dependent variable is related to a set of independent variables M.

Logistic regression is an iterative resource that facilitates the identification of the coefficients necessary to calculate the maximum probability associated with a given event, that is, it is a way of estimating probability distribution parameters that maximize the likelihood function. Therefore, to perform logistic regression, computational resources are used and, in this work, IBM® SPSS software was used to carry out such estimates and all the calculations involved. Regarding the configuration of the analysis output data, it was selected to present the confidence interval at 95%, show the Hosmer-Lemershow goodness of fit and the classification cutoff at 0.656 according to the percentage of companies that have time monitoring real.

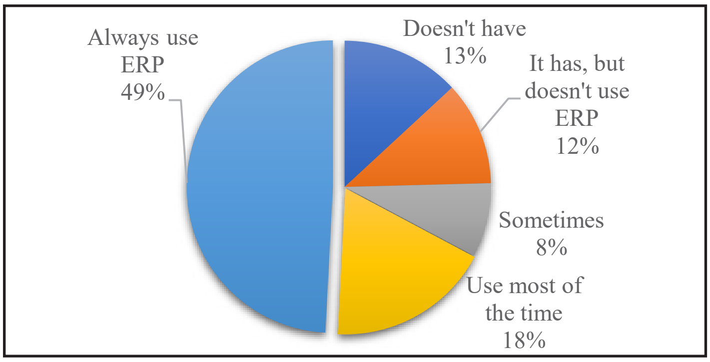
5 RESULTS AND DISCUSSION

When analyzing the results of the survey, the first responses are of an informational nature, so 30% of respondents come from large companies and 70% from medium-sized companies. Seventy-seven percent (77%) of respondents are over 30 years old and 80% have completed higher education. It was identified that 84% of people work directly in the Production Programming and Control (PCP) area, which demonstrates the significance of the responses, as the work focuses on the manufacturing area and, according to, the PCP is the one responsible for issuing and sequencing Production Orders, controlling production capacity, among other planning. Additionally, 79% of respondents have five years or more of experience in the area.

Furthermore, the majority of respondents said they had never participated in research related to Industry 4.0. In this sense, according to the data analyzed from the survey research, it is possible to classify the Textile and Clothing industries of Santa Catarina in the second and third level in the maturity model according to , in which at this level there is the generation and processing of information only.

Regarding the use of ERP to plan the availability of raw materials and intermediate stocks or manufacturing capacity planning, 49% of responding companies use "always", in 26% the use is "sometimes" or "most of the time" and, in 25% of companies "there is no ERP system" or "they do not use it", as shown in Figure 5. In this sense, it can be seen that only half of the respondents have their planning areas making use of integral form of this Information and Communication Technology, which compromises the full industrial manufacturing performance. According to ERP aims to assist decision-making in an evolutionary and integrative way in the management of operations in an analogy of the brain that controls the activity factory planning.

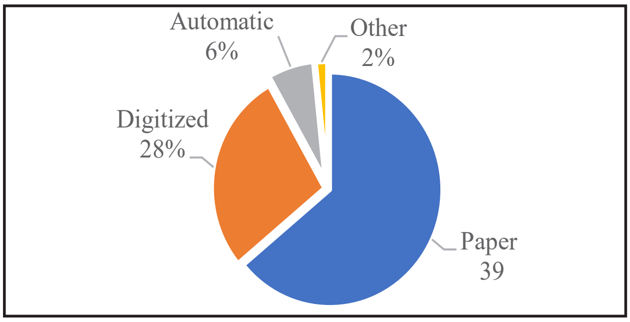
Figure 5 – Factory planning using ERP



Source: by the authors

According to the digitization of production orders brings information more quickly and reliably , without the need for space for archiving physical resources and reducing paper costs. Furthermore, comment that the adoption of a MES, for example, manages several activities on the factory floor and completely avoids the work of issuing production orders on paper, being a tool for change at an organizational level. Thus, one of the characteristics of the use of Information and Communication Technologies is the digitalization of information and the format for issuing production orders. However, for 64% of responding companies, production orders are issued "on paper" as can be seen in Figure 6. Out of the companies that have a digitalized or automatic way of issuing production orders, only 9 responded and all of them are considered large.

Figure 6 – Production Orders Issuance

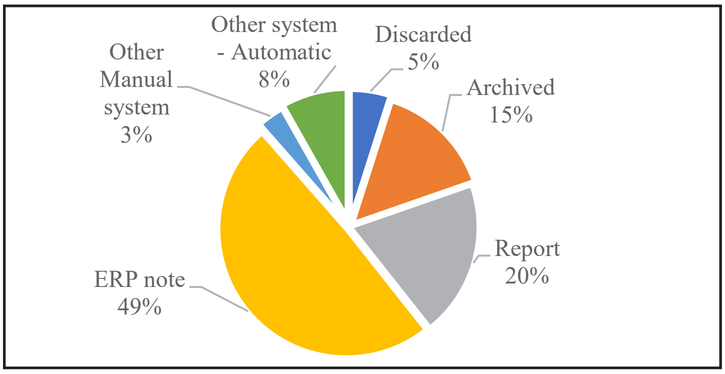


Source: by the authors

Another relevant feature for a smart factory is the destination of production orders during or at the end of the process execution. Figure 7 shows that 49%

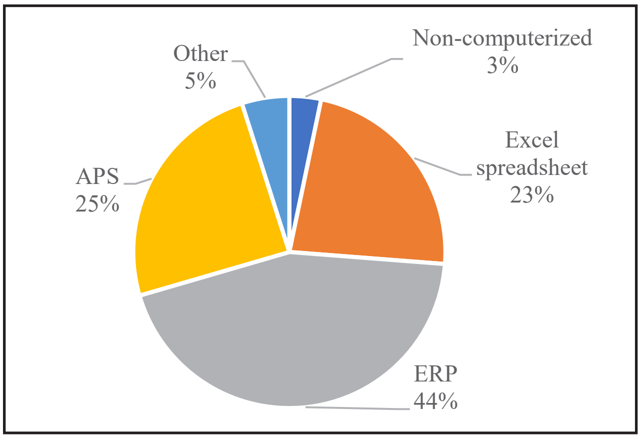
"note production orders in the system", 20% "feed a report on compliance with the production schedule" and 20% "discard" or simply "archive" production orders without taking advantage of the data, and only 8% providing "automatic feedback to the system". According to , feedback has a positive impact on productivity and according to feedback loops are essential for the functioning of a PCPS.

Figure 7 – Destination of Production Orders



Source: by the authors

Figure 8 – System used in PCP

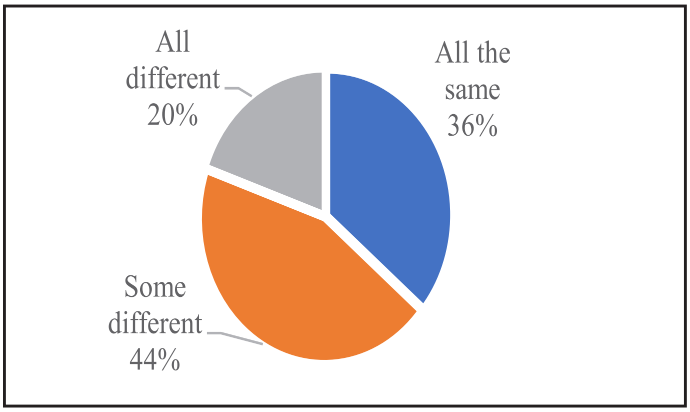


Source: by the authors

Regarding the system used for the PCP in Figure 8, it is possible to identify that in 26% of companies the system is "non-computerized" or uses "Excel spreadsheets", which are not recommended for these activities. However, 69% of companies use ERP or APS to carry out Production Scheduling, with 13 of these being large and 32 responding medium-sized companies. According to the single use of ERP is flawed because it ignores capacity constraints, according to APS meets this need to generate a viable plan, but essentially the two must work in an integrated way. However, programming systems are essential to achieve efficiency in manufacturing planning.

The production programming logic, in turn, is the way in which the system must execute and adapt the algorithm and operating parameters of the PCP. The research results showed that 37% have the same form of programming for all stages, such as shown in Figure 9. According to , the diversity of complex processes in addition to a variety of databases or spreadsheets developed on the factory floor make systems unresponsive.

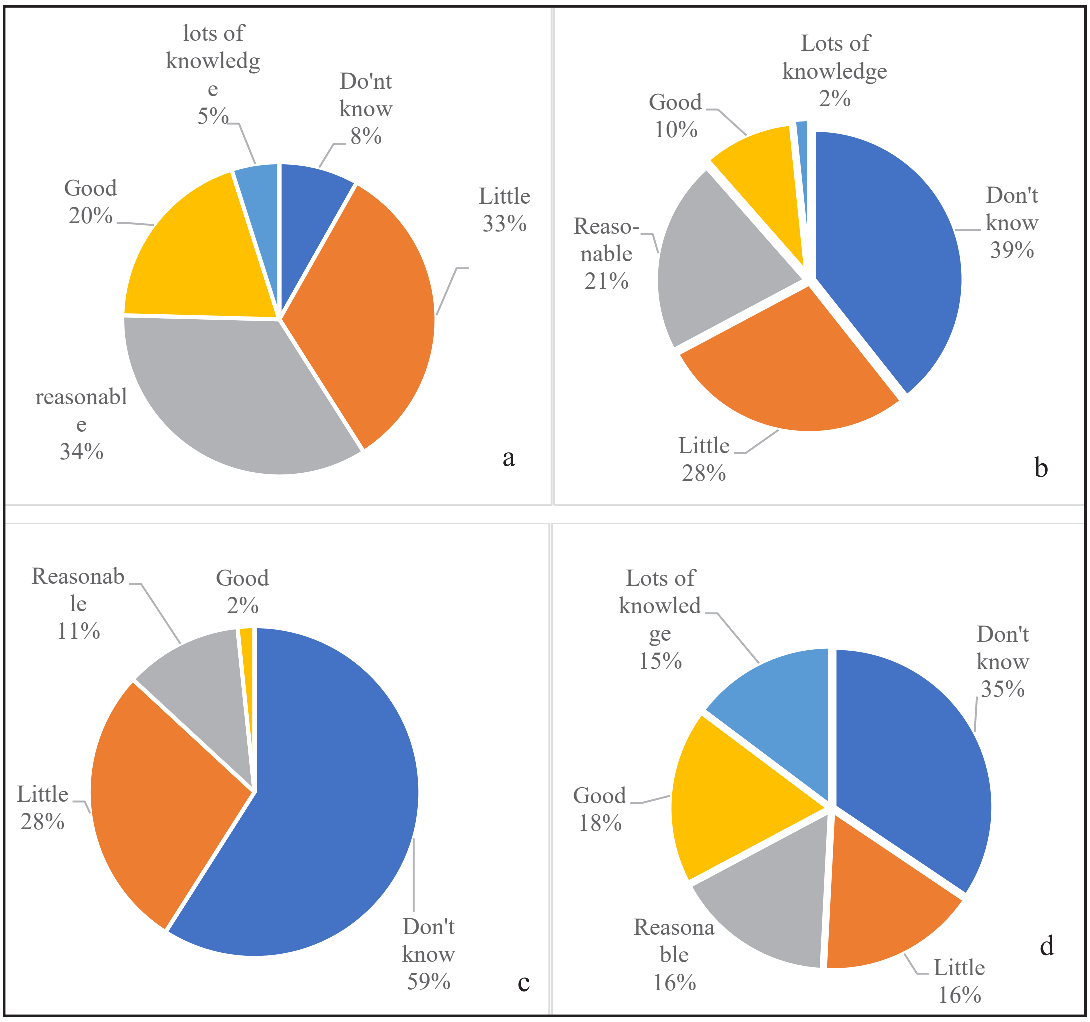
Figure 9 – Production Scheduling Logic



Source: by the authors

Figure 10 shows the level of knowledge related to PCPSs systems. Thus, knowledge about Industry 4.0 is "very good" or "good" in 25% of the companies evaluated, in relation to MES software 12% of respondents have knowledge, about CPDs only 2% of managers and RFDI with the highest index reaching 33%. This reinforces what was exposed by that the difficulty in the evolution and implementation of smart factories lies in the restricted issue of knowledge about Industry 4.0, for this is an area that demands research, both in industry and academia. In the view of research on CPSs is still in its infancy within the textile and clothing industries.

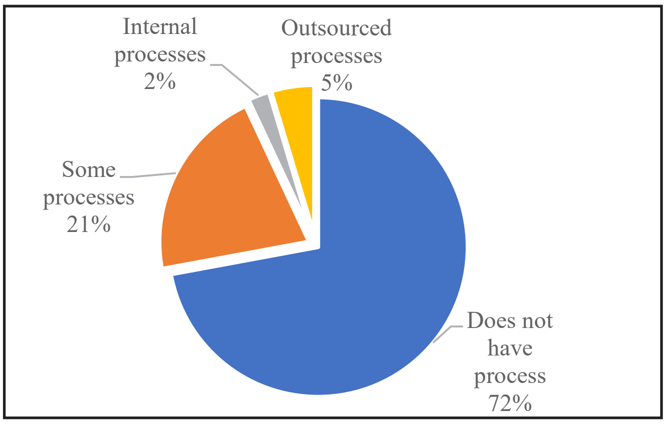
Figure 10 – Knowledge of technologies related to CPSs (a-industry 4.0; b-MES; c-CPS; d-RFID)



Source: by the authors

Although knowledge about RFID presents a high level of expertise, when compared to MES and CPDs, its application in batch tracking is low, as in Figure 11 it is possible to see that 72% of companies do not have this technology implemented. The remaining companies have internal tracking (2%) and in some processes (21%), only 5% identify outsourced processes. The literature pointed out the benefits of this technology, with its patent dating back to 1930s and the technology was popularized in 2003, with low cost and access T, but the textile and clothing industry does not implement representatively in its processes, nor in the manufacturing sector, which is practically the end of the chain. This note can be derived from the heterogeneity of this chain and the low technical and managerial quality that permeates the sector.

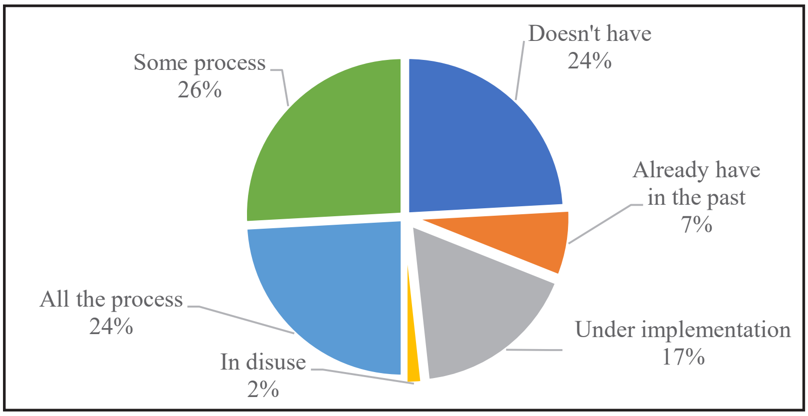
Figure 11 – Use of RFID technology



Source: by the authors

Regarding company sectors with real-time monitoring, Figure 12 shows that 24% of companies "do not have" or 7% "already have" real-time process monitoring. On the other hand, 24% have monitoring "in all processes" or 26% in "some processes". According to the real-time monitoring process is used to visualize, analyze and control the process on the factory floor. Basically, it is essential for a smart factory, as it facilitates the flow of information, improves the flow of materials and reduces cycle times of manufacturing.

Figure 12 – Use of monitoring system



Source: by the authors

Furthermore, out of the companies that use online monitoring, most of them monitor production orders (75%), quality (21%) or predictive maintenance (4%). The authors add that monitoring production orders in real time provides greater transparency and speed of information available to managers, suppliers or customers who carry out related actions on the factory floor. Among the advantages of real-time monitoring systems, we have the generation of reliable data, batch tracking, agility on the factory floor and increased productivity.

Some examples of monitoring are given by which exemplify its use in detecting faults in weaving or sewing faults in clothing. present applications in wiring to generate intelligent maintenance diagnosis. demonstrate that predictive technologies through intelligent algorithms can be used to predict machine performance degradation. However, the results indicate that the textile and clothing industry has a long way to go to achieve high rates of real-time monitoring of its processes. For this to occur, the development of a mathematical model to identify companies' adaptation variables to cyber-physical production systems is crucial.

6 CONCLUSION

This article aimed to verify how the Textile and Clothing sector is adapting to the use of technologies aimed at CPS. For this, a survey was developed and applied to 61 medium and large companies in the state of Santa Catarina. Thus, this diagnosis showed that this sector still has many opportunities for improvement.

The information management used by the planning area showed that 50% of companies always use ERP, which hampers planning accuracy, as they do not use a database integrated with the company's other data. Furthermore, less than 15% have their POs digitized or provide feedback to the system automatically. Another issue is the use of APS in Production Scheduling, with only 25% able to do the scheduling, taking into account the restrictions of the production process and approximately 35% follow the same form of scheduling for the entire company. This scenario reflects that 60% are practically unaware of CPS or MES technologies.

Another point observed was the real-time monitoring of the manufacturing process, which is the basis of a CPSs system. The results showed inefficiency as approximately 25% of companies have monitoring at all stages. The sector with a high rate of real-time monitoring in the textile and clothing chain was the processing, the justification may be centered on the specificity of production, as some companies only carry out this manufacturing process. However, there is evidence that companies are beginning to implement real-time monitoring. From this real-time monitoring, it was also possible to conclude that the majority of responding companies use the system to monitor the execution of production orders in real time and interconnected with the ERP, making the data available in the cloud.

In general, almost half of the respondents indicated that they are adapting to Industry 4.0, but the lack of knowledge on these technologies, the reduced rate of use or isolated use demonstrates a long implementation path for companies to become smart factories. Although the scenario shows that companies are not adapted, there are few companies that can be used as case studies, which is also a suggestion for future work, that is, to explore how adapted these companies are to a PCPS system.

This work does not intend to exhaust all scenarios within the Textile and Clothing industries, but, from both, academic and managerial point of view, to serve as a theoretical and practical reference in research related to CPS. Furthermore, the survey cannot be generalized to represent the whole sector, being indicated as an opportunity to identify best practices and thus motivate companies to identify their weaknesses and strengths. Future work may expand benchmarking to companies in other segments and locations.

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APPENDIX

Appendix A and B are available at: https://drive.google.com/file/d/1J7qqvyNCdu FWJgMFNOxr7JNRGs9pDQr8/view?usp=sharing

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1. Definition of research problem	√	√	√	√	
2. Development of hypotheses or research questions (empirical studies)	√	√	√	√	
3. Development of theoretical propositions (theoretical work)		√			
4. Theoretical foundation / Literature review	√	√		√	√
5. Definition of methodological procedures	√	√	√	√	√
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9. Critical revision of the manuscript	√		√		
10. Manuscript writing	√				
11. Manuscript revision	√		√	√	√

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The authors have stated that there is no conflict of interest.

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