Journal of Mechatronics Engineering

Discrete Event System Decision: an Approach to the Corrective Maintenance of a Machine Based on Colored Petri Net

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DOI: 10.21439/jme.v6i1.113

Abstract. Industrial processes, over the years, need to be modernized to reduce costs and maintain product quality. In this context, new tools or techniques have been developed for such an event to further improve industrial processes and the quality of the manufactured product. This paper refers to the application of a graphical and mathematical modeling tool, in this case, the Colored Petri Net (CPN), applied to a corrective maintenance process of a conical machine in the textile industry. That is, the corrective maintenance process is modeled as a discrete event system for decision-making to identify which task must be performed to perform corrective maintenance. It also presents the operation of CPN for the described process, the general concepts of maintenance applied to the textile industry, the theory about PN, as well as the modeling of the process. The results show the mathematical model of the PN and the CPN graph, modeled for the maintenance process, which will facilitate the understanding of the maintenance process, as well as solve future problems more quickly and with quality. Finally, it is concluded that the model carried out can be used as a decision-making system to facilitate the corrective maintenance process.

Keywords: Colored Petri Net. Modeling. Corrective maintenance. Conical machine. Textile industry.

1 Introduction

Industrial production processes, over the years, are becoming more efficient to reduce costs and improve product quality. So that these processes can always remain in good working order, maintenance programs must be well planned and executed, for this, it is necessary to make the right decision in certain activities. With the advances in technology, more and more techniques and processes have been improved in industrial applications, such as the modeling of these processes using models with discrete event systems (ZIRONDI; OKADA, 2021).

The accelerating change in technology, industries, and social patterns and processes, caused by ubiquitous digitization, greater interconnectivity, and intelligent automation, commonly referred to as the Industry 4.0 revolution, has presented greater challenges for system maintenance issues than ever before (HRISTOSKI; DIMOVSKI, 2023).

Certain managerial decision problems are generally not easily modeled using traditional decision-making frameworks. Complex management decision problems can have characteristics that are difficult to fully describe with any single decision-making framework, such as a decision tree or a network model. A Petri Net is a powerful and highly versatile modeling tool that has meta-model capability to substitute alternative decision-making structures and to model complex management decision problems or situations (BYEON et al., 2023; LIU et al., 2023).

Discrete event system models (DESs) can be grouped into two main classes. Non-timed models are those models where the order of states or events is relevant in the design and control specification. The specific time instants at which state transitions and events occur are not considered. Timed models are intended for the study of properties explicitly dependent on the time between events. Petri Nets are effective for modeling non-timed and timed DES, particularly when there is a high degree of concurrency and synchronization (LIU; LI; LI, 2023; LI; CHEN; LI, 2023).

The dissertation defended by Carl Adam Petri, in 1962 at the Faculty of Mathematics and Physics of the Technical University of Darmstadt, Germany (MURATA, 1989) gave rise to the appearance of the Petri Net. This tool is very recent and its function is to graphically and mathematically model several systems favorably, to describe and study notions of discrete event systems and simultaneous evolutions. Petri Nets can be applied in many different areas, such as manufacturing systems, software development, administrative systems, etc. (HOLANDA et al., 2019).

The objective of this work is to carry out the modeling in Colored Petri Net of the corrective maintenance, carried out in a conical machine textile machine. To carry out this activity, the software CPN (Colored Petri Net) Tools will be used, which makes it possible to carry out the modeling and simulations of the model, which was found from a flowchart built with the possible tasks carried out during corrective maintenance. Through the simulations, analyses of critical points in maintenance will be carried out, and the possibility of reducing the time to discover a defect not previously found in the machine.

1.1 Importance of work

The motivation for carrying out this work was the need to find some critical points during the corrective maintenance of a machine in the textile industry. Many times a problem encountered can happen again and one can forget how the problem was solved. With a mathematical and graphical model of the maintenance process, many tasks can be easily solved and problems can be recorded for future maintenance.

The main contribution of this article is the implementation of a model in Colored Petri Net using CPN Tools, which is a free *software*, for the corrective maintenance of a conical machine. The idea of having a model is that it can be updated, and it can help in making critical point decisions during maintenance. Finally, some simulations of the model are presented, from which it is possible to decide on the task to be carried out in maintenance.

1.2 Work organization

This section has the introductory purpose of presenting the work, and the remainder of this article is structured as shown next. Section 2 presents the literature review about CPN applications. Section 3 presents theoretical concepts related to Petri Nets and industrial maintenance. Section 4 presents the methodology adopted in this work, the description of corrective maintenance, and how the Petri Net was implemented. The results and discussions will be presented in Section 5, and finally, the Conclusion will be presented in Section 6.

2 Literature Review

In this section, the literature review that supports this work is presented.

In the research of Hussain et al. (2023) a method was presented to discover a Petri Net model interpreted by data (discover a data-interpreted Petri net - DIPN) of an ICS (industrial control system) from the observed input/output signals of the controller. A DIPN model combines a Petri Net and differential equations that are commonly used to model discrete event-driven processes and continuous time-driven processes. Therefore, the main contribution of our work is to discover guards in event transitions that serve as the link between the discrete automatic control layer and the continuous processes of the physical layer of an ICS. With the method, the identification of systems was carried out to discover models of discrete and continuous processes, that is, Petri nets and differential equations.

In Hristoski e Dimovski (2023), an overview of various maintenance strategies, supported by proposed models of Petri Nets, was presented. The simulation models were adequate to carry out analysis of performance and availability of the strategies, based on a multitude of input parameters. The suggested Petri Net models provided solid frameworks for investigating the effectiveness of various maintenance strategies applied to a wide range of systems.

Innovations and technological advances create new opportunities to operate and maintain factories, which we call digitized manufacturing. This development is recognized as a socio-technical system change (STS), where a change in objectives, technology, processes, people, or environment of the production system can lead to cascading effects between these subsystems (PINCIROLI; BARALDI; ZIO, 2023). In the article by Lundgren et al. (2023) a study was developed on leadership in industrial maintenance from an STS perspective. The research was conducted through an exclusive interview in which twenty maintenance managers from the Swedish manufacturing industry offered their perspectives on the changing leadership in maintenance, providing a unique insight into the challenges facing maintenance leaders in digitalized manufacturing.

In (KAID et al., 2023) was proposed a methodology for the implementation of Ladder Diagram (LD) in automated manufacturing systems (AMSs). A colored resource-oriented Petri net (CROPN) was developed for modeling and guaranteeing the deadlock-free behavior of AMS. After a ladder diagram, CROPN (LDCROPN) was constructed to transform the CROPN into an LD. The proposed LDCROPN was assessed using instances from the literature. The results show that the LDCROPN was effective, has a simpler structure, and has less computational overhead than existing techniques.

In (BREZOVAN et al., 2023) was proposed an approach to the Colored Petri Nets (CPN)-based control is. CPN was used for modeling the dynamics of both the controller and the controlled process in the control system structure. The mathematical model of the controlled process was discretized to use CPN in modeling the controlled process and the control system as well. The proposed controller implemented a Moore automaton. The theoretical aspects of the controller design were presented in the paper, as well as aspects of the system controllability. The level control of three-tank systems was considered to validate the proposed controller. Extensive simulations were performed using the CPN Tools tool and experimental results on laboratory equipment were included.

3 Theoretical Foundation

In this section, the theoretical foundations that support this work are presented, which are the subjects related to Petri Nets and industrial maintenance.

3.1 Petri nets

Petri Nets (PN) is a mathematical and graphical tool for modeling DESs. They are like a systems modeling language that graphically defines the structure of a distributed system as a directed graph with two types of nodes: places and transitions, and directed and weighted arcs connecting places to transitions and transitions to places, as well as tokens (integers positive) associated with places (MACIEL; LINS; CUNHA, 1996).

A PN is a graphical tool for the description and analysis of concurrent processes that arise in systems with many components (distributed systems). Graphs, along with rules for thickening and refining them, were invented in August 1939 by the German Carl Adam Petri (PETRI, 1966).

According to Gu e Bahri (2002), PN is a powerful mathematical and graphical tool in the description of event-driven systems, that is, discrete (dynamic) event systems. These systems can be asynchronous, contain sequential and concurrent operations, and involve deadlocks, mutual exclusion, and non-determinism. Investigation of Petri Net applications in industrial engineering systems, particularly manufacturing systems, began in the early 1980s. Since then, Petri Net methodology and its applications in automated manufacturing systems have been widely explored, and several results have been observed.

In an industrial manufacturing system, the product is typically composed of discrete parts, and the behavior of transforming raw materials into finished products is dominated by discrete event activities. The range of problems encountered in its design and operations are mostly event-related or event-driven (RECALDE et al., 2004).

The structure of Petri Nets is composed of some basic elements such as places, transitions, tokens, and arcs. The places (represented by circles) are passive components and related to some state variable of the system; transitions (represented by bars or rectangles) are active components that correspond to some action performed within the system; the tokens (represented by a dot in a place) is an indicator signifying that a condition associated with the place is checked; and finally, the arcs (represented by arrows) connect places to transitions and vice versa. Carrying out actions is associated with preconditions or conditions of the system's state variables, that is, there is a relationship between places and transitions, which makes it possible to perform a certain action (CARDOSO; VALETTE, 1997).

In Figure 1 a graphical representation of the elements of a Petri Net is presented (CALLOU et al., 2012).

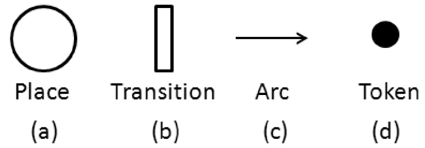

Figure 1: Elements of a Petri Net. (a) Place, (b) Transition, (c) Arc, and (d) Token.

Formally, a Petri Net is a quintuple, a set with 5 subsets, i.e.,

$$PN = (P, T, A, W, M_0), \quad (1)$$

where:
- $P = \{p_1, p_2, \ldots, p_m\}$ is a finite set of places;
- $T = \{t_1, t_2, \ldots, t_n\}$ is a finite set of transitions;
- $A \subseteq (P \times T) \cup (T \times P)$ is a finite set of arcs;
- $W : A \to 1, 2, \ldots$ is the weight function associated with the arcs;
- $M_0 : P \to 0, 1, 2, \ldots$ is the starting mark.

In Figure 2 a simple example of a transition-place Petri net is presented (CALLOU et al., 2012).

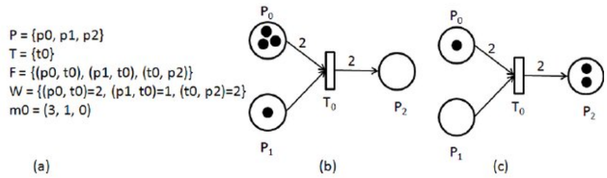

Figure 2: Example of a transition-place Petri net. (a) Mathematical formalism, (b) Graphical representation before the firing of t_0, (c) Graphical representation after the firing of t_0.

A different type of place-transition PNs are Colored Petri Nets (CPN), which are a combination of Petri Nets and programming language. It was developed at the University of Aarhus – Denmark. CPNs are considered a language for modeling systems where synchronization, communication, and shared resources are important. They have the ability to model complex systems and provide models with a high level of abstraction and better graphical representation capability. They are able to reduce the size of the Network, modeling all similar processes in a single Network, instead of having a separate Network representation for each process or component (CARDOSO; VALETTE, 1997).

Figure 3 shows an example of a Colored Petri Net made using CPN Tools software.

3.2 Industrial maintenance

Maintenance, even without being noticed, has always existed, even in more remote times (PEREIRA; NEVES, 2011). It began to be known by the name of maintenance around the 16th century in central Europe, along with the emergence of the mechanical watch, when the first technicians in assembly and assistance appeared. It took shape throughout the Industrial Revolution and was established, as an absolute necessity, in the Second World War (PIEDADE, 2012; RODRIGUES; MARÇAL, 2011; MORO; AURAS, 2021).

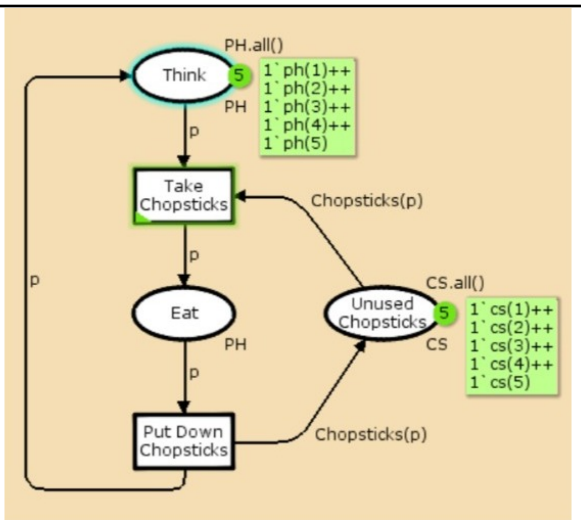

Figure 3: Example of a Colored Petri Net.

The term “Maintenance” has its origins in the military vocabulary, whose meaning was to “maintain”, in combat units, manpower, and material at a constant level. The term “Maintenance” appeared in the industry around 1950 in the United States, and it has been overlapping with the term “conservation” (MONCHY, 1989).

The ethnology of the word maintenance presents its Medieval Latin origin *manutentione* - "action of holding with the hand", or probably of French origin *manutention* - "action of maintaining". However, it is understood as the act or effect of maintaining or conserving a physical asset (MOURA, 2007).

Slack et al. (2009) describe that maintenance is the term used to demonstrate how organizations try to avoid failures by taking care of their physical facilities. This concept highlights failure prevention and recovery, an important area of maintenance activity, although it does not involve its full scope.

The modern concept of maintenance is to guarantee the availability of the function of equipment and installations to meet a production process and preserve the environment, with reliability, safety, and adequate costs. Maintenance should be seen as a strategic function in obtaining results for the organization and should be directed towards supporting management activities and solving problems presented in production (KARDEC; NASCIF, 2001).

Maintenance is an extremely important activity for the useful life of an equipment, as well as ensuring that it works efficiently. According to NBR-5462 (1994), there are three main types of maintenance, which are: corrective, preventive, and predictive.

3.3 Corrective maintenance

Unexpected corrective maintenance is that which aims to locate and repair sudden defects in equipment that operates under continuous work. Occasional corrective maintenance: This consists of repairing faults that do not stop the machine. They occur when a machine stops, for a reason other than a defect, such as, for example, in the case of a delay in the delivery of raw materials (KARDEC; NASCIF, 2001; ARAÚJO et al., 2021).

Unplanned maintenance, is carried out after the detection of damage, or planned, to replace equipment before it goes into operation or with a view to improvement activities. In some situations, it is identical to corrective maintenance, with the addition of improvement actions being developed together with the repair. These actions are already a maintenance activity of a technical, administrative, and management nature (AMARAL, 2016).

In a more detailed scope, it dedicates itself to the study and design of equipment, to avoid the occurrence of new emergency disturbances. Occasional corrective maintenance is carried out when there is a machine stoppage, for reasons other than a defect, such as, for example, in the case of a delay in the delivery of raw materials, and consists of repairing faults (KARDEC; NASCIF, 2001).

Corrective maintenance consists of repairing damage when it occurs. This type of maintenance has some inopportune characteristics, the most significant of which are (MORO; AURAS, 2021):

- The urgency of the fault does not allow for the correct assessment and preparation of the work to be carried out;
- The maintenance crew has an irregular workload.

It is justified when the items targeted for maintenance are not critical to production or the costs in the event of a breakdown do not justify other means of action.

3.4 Preventive maintenance

Preventive maintenance is actions planned at predetermined intervals, based on the useful life of components, to reduce the probability of equipment failure. In this way, unscheduled stops can be avoided.

It is necessary to emphasize that NBR-5462 (1994) recommends taking care of the maintenance and reliability aspects of the equipment. Therefore, it involves actions of a technical, administrative, and supervisory nature in order to maintain or replace the equipment.

In short, it consists of carrying out planned maintenance in certain periods, according to established criteria. Examples of preventive maintenance on machines and equipment:

- Screw tightening;
- Inspections of bearings during operation;
- Replacement of worn parts;
- Lubrication;
- Cleaning;
- Adjustments, among others.

However, it is important to emphasize that this type of industrial maintenance is specifically suited to problems related to the useful life of the equipment (PEREIRA et al., 2009).

3.5 Predictive maintenance

Predictive maintenance seeks to monitor the parameters that characterize the operating state of the equipment, involving procedures, measurement techniques, and appropriate instrumentation, monitoring, and analysis. Predictive maintenance is one of the most efficient arrangements when you want to prevent and anticipate problems in a company's machinery. With it, the company will have greater operational applicability on the factory floor, and reduce costs, errors, and delays in the production process (MORO; AURAS, 2021).

Some of the most common predictive maintenance techniques can be highlighted, such as:

- Vibration analysis;
- Ultrasound;
- Thermography;
- Oil analysis;
- Noise monitoring;
- Laser shaft alignment;

- Machine condition monitoring (by measurements in the plant with scheduled visits and/or *online*);
- Industrial endoscopy.

Despite being one of the best types of maintenance, there are some disadvantages that can be highlighted (MORO; AURAS, 2021):

- High dependence on technology to run it;
- High investment in the purchase of equipment and training;
- Not suitable for non-critical equipment.

4 Methodology

This section presents a description of the conical machine, the corrective maintenance on this machine, and the implementation of the model in Colored Petri Net in CPN Tools.

4.1 Conical machine

Textile yarn is the final product of the spinning stage, and its main characteristic is its diameter or thickness (technically called the yarn strength). The textile thread can be manufactured from natural, artificial, and synthetic fibers, which are the raw materials used. Regarding the type of raw material in Brazil, it is found that around 70% of this fiber is cotton, 25% artificial and synthetic fibers, and 5% linen, wool, silk, and others.

Next, the textile production process and its characteristics will be discussed; the main component links of the (MONTEIRO; SANTOS, 2002) textile chain will also be described. The definition of the textile production chain has its basic contours defined in Figure 4 next.

From the spinning sector, the bobbins go to the conical machine (machines I work with), which has the purpose of purging the yarn, that is, removing existing defects and transferring the yarn from the bobbins to the bobbins (cardboard cones). Winding in the conical machine consists of passing the yarn contained in a bobbin to a bobbin or cone, which will have the most suitable shape, capacity, and size for a subsequent operation that is to be carried out (weaving or knitting). This operation is also used to carry out a depuration, that is, the elimination of defects in the thread, such as thin and weak points, thick points, neps (agglomeration), and knots.

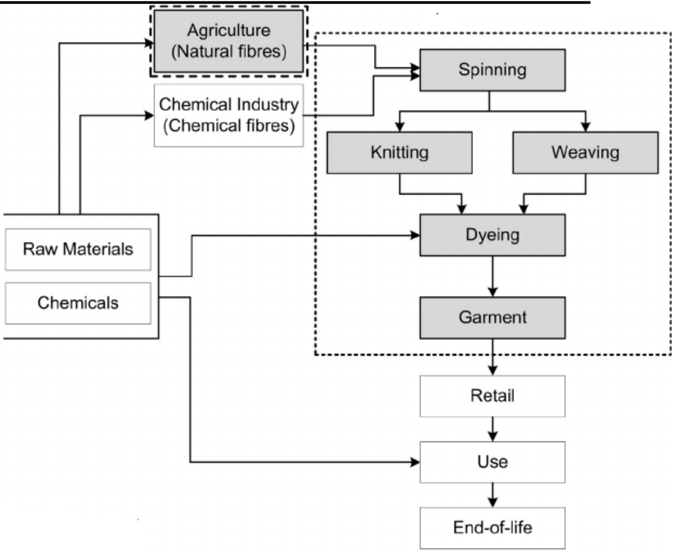

Figure 4: Process of a textile production chain.

The conical machine can transfer yarn from the bobbin coming from the ring (or conventional) spinning machines to the spools or cylindrical spools, enabling better performance in the subsequent processes of the textile chain. Figure 5, next, shows a conical machine textile.

Figure 5: Conical machine textile.

4.2 Conical machine corrective maintenance

In order to carry out the corrective maintenance of the conical trees, it is necessary to dismantle and assemble the electronic boards, adjust machine parameters, install software, and maintain and repair electrical appliances and equipment specifically in the conical trees, following a work instructions (WT), such as stepper motors, signal transmitters, and receivers, debugging sensors, replacing printed circuit boards (such as fonts, CPU, communication driver, repairing sensor cables).

Assembly, adjustments, installations, maintenance, and repair of electrical appliances and equipment specifically in *conicaleiras* following a WT. Such as stepper motors, signal transmitting and receiving devices, debugging sensors, replacing printed circuit boards (such as fonts, CPU, communication driver, repairing sensor cables), to perform corrective maintenance.

To carry out corrective maintenance, first, the service order (SO) requested by the responsible department is received. Figure 6 shows the corrective maintenance flowchart for the conical machine.

4.2.1 Security recommendations

To replace equipment, plates, and parts, in addition to keeping the equipment turned off, it is also essential to promote the safe de-energization of conical machines. In the industrial area, any activity related to replacing equipment or parts, maintaining electrical installations, repairing polishers, or adjusting machines requires that the equipment be turned off. However, switching off alone does not guarantee complete safety, requiring a process known as safe de-energization of conical machines.

To de-energize a circuit breaker in conical machines, it is necessary to carry out a series of procedures so that the professional has complete safety when handling a particular machine. Therefore, according to Regulatory Standard 10 (BARROS et al., 2010), only electrical installations that comply with the following sequence next are considered de-energized:

1. Sectioning - is the act of enabling total electrical discontinuity, with adequate distance according to the voltage level in question, between one circuit or device and another. It is obtained by activating an appropriate element (disconnect switch; switch; circuit breaker), activated by manual or automatic means.

2. Preventing reenergization - establish orders that guarantee, and prevent the unwanted reversal of the sectioning carried out, aiming to ensure the professional has control over that sectioning. Through the application of mechanical locks, padlocks, and signage signs.

3. Measuring the absence of voltage - characterized by verifying the effective absence of any voltage in the circuit conductors. The check must be carried out with tested meters (multimeters, clamp meters) to check whether there is a voltage or current level in the conductors, and can be carried out by contact or by approach, and in accordance with specific procedures.

4. Promote temporary grounding with equipotentialization of the conductors of the machine circuits.

5. If the absence of voltage is detected, a conductor from the temporary grounding set must be connected to the earth and neutralize the system. All energized elements, located in the controlled area, must receive suitable insulation (blankets, gutters, covering with insulating material, etc.) to avoid accidents caused by contact.

6. Reenergization impediment signaling. For safe de-energization in the industrial environment, appropriate safety signs are adopted, designed to warn and identify the reason for de-energization and information from those responsible for the procedure. Such as cards, warnings, or labels signaling locking or blocking.

According to NR10 (2019), the de-energized installation state must be maintained until authorization for re-energizing, with this process respecting the sequence of procedures listed next:

1. Removal of tools, utensils, and equipment from the site. Remove all material and utensils used during the process out of the controlled area, to then allow the facilities to be released.

2. Remove all workers not involved in the re-energization process from the controlled area.

According to regulatory standard NR 10 (NR10, 2019), professionals cannot, from this stage onwards, intervene in the facilities or remain in the controlled area (CUNHA, 2010). The following procedures must be followed:

1. Removal of temporary grounding, bonding, and additional protections. This consists of removing materials used to protect energized parts close to the workplace and utensils used to maintain equipotential bonding.

2. Removal of re-energization prevention flag; consists of removing signs and warnings preventing re-energization.

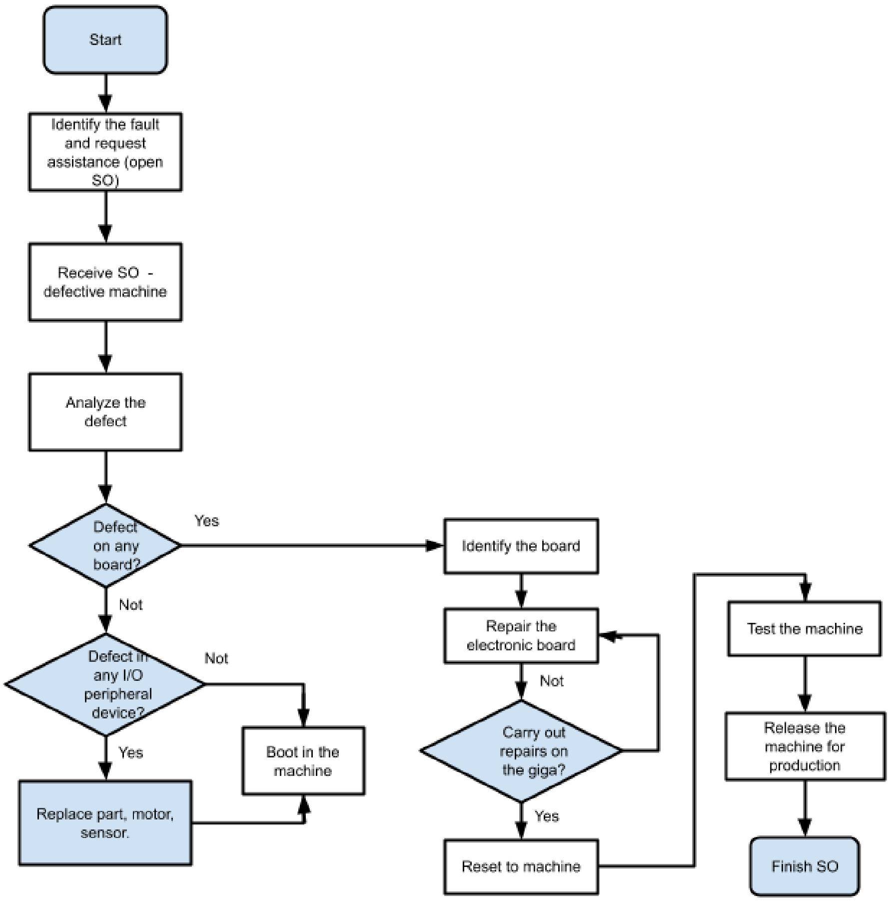

Figure 6: Flowchart of the procedure for carrying out corrective maintenance on the conical machine.

3. Unlocking and restarting the machine; removal of blocking items and reinsertion of conductive elements that were removed to ensure non-reconnection and finally the re-energization of the circuit, reestablishing the working condition of the cones.

4.3 Implementation of the CPN model in CPN Tools

In order to carry out the modeling of the maintenance process in Colored Petri Nets, it was necessary to organize the places and transitions of the process. Table 1 presents places of the maintenance process shown in Figure 6, demonstrating the states before and after each firing of a transition. Table 2 illustrates the process transitions that represent the actions performed, that is, the stages of the maintenance process.

By connecting places to transitions, arcs are determined, which form a set of information. Another important element is the tokens, which act as rules for triggering transitions, characterizing the Colorful Petri Net. In the initial marking of the Network, a token is defined that represents the beginning of the maintenance process until the end of a task, which in this case triggers a (CARDOSO; VALETTE, 1997) transition.

For modeling, CPN Tools was used, which is a free software for modeling Petri Nets that enables simulations of modeling and operation of the model, in addition to enabling a graphical representation of the model in a Colored Petri Net. The arc tokens and expressions are written in the CPN ML programming language (Colored Petri Nets Meta Language).

Figure 7 presents the declarations and definitions of the colors and tokens used in the CPN model, for modeling the corrective maintenance process.

Table 1: Description of the places (states) of the maintenance process.

Places	States	Description
p1	Receipt of the SO	The SO is handed over to the maintenance sector for verification of the problem
p2	Defect analysis	The defect is identified for further correction
p3	Defect analyzed	Analysis of which problem may have caused the defect
p4	Board defect identified	Defect identification for subsequent correction
p5	Board repair	Board maintenance to correct the defect
p6	*Boot* performed	Performing *boot* on the machine
p7	Repair carried out	Completion of the repair on the board
p8	Test carried out	Finalization of repair on the board
p9	SO completed	Maintenance finalized and machine released

Table 2: Description of the transitions (actions) of the maintenance process.

Transitions	Actions	Description
t1	Analyze SO	Perform SO analysis to check for possible defects
t2	Identify defect	Identification of the defect after functional test verification
t3	Check engine	Check whether the engine, sensor or other parts are defective
t4	Perform *boot*	Perform *boot* on the machine
t5	Check board	Check for possible defects on the board
t6	Repair board	Repair the board after identifying the defect(s)
t7	Carry out tests	Carry out functional tests on the machine
t8	Replace parts	Replace part, motor, sensor
t9	Complete OS	Release the machine for production and finalization of the SO

Figure 7: Declarations and definitions of colors and model tokens in CPN.

5 Results

As presented in the Methodology (Section 4), the process of carrying out corrective maintenance, here the result of the modeling in CPN is presented, that is, the model in the form of a graph.

Figure 8 presents the CPN model of the maintenance process of the conical machine textile machine, which represents a tool for automating the corrective maintenance process.

The mathematical model of PN presented in Figure 8, can be described as presented in Equation (2), next.

$$
\begin{aligned}
P &= \{p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9\}, \\
T &= \{t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8\}, \\
A &= \{(p_1, t_1), (t_1, p_2), (p_2, t_2), (t_2, p_3), \\
&(t_2, p_4), (p_3, t_3), (p_4, t_4), (t_3, p_5), \\
&(t_4, p_6), (p_5, t_5), (t_5, p_5), (p_5, t_6), \\
&(t_6, p_7), (p_7, t_7), (t_7, p_8), (p_8, t_8), (t_8, p_9)\}, \\
W &= \{[(p_1, t_1), 1], [(t_1, p_2), 1], [(p_2, t_2), 1], \\
&[(t_2, p_3), 1], [(t_2, p_4), 1], [(p_3, t_3), 1], \\
&[(p_4, t_4), 1], [(t_3, p_5), 1], [(t_4, p_6), 1], \\
&[(p_5, t_5), 1], [(t_5, p_5), 1], [(p_5, t_6), 1], \\
&[(t_6, p_7), 1], [(p_7, t_7), 1], [(t_7, p_8), 1], \\
&[(p_8, t_8), 1], [(t_8, p_9), 1]\}, \\
M_0 &= \{2, 0, 0, 0, 1, 0, 0, 0, 0\}^T.
\end{aligned} \tag{2}
$$

The CPN model was simulated using the software

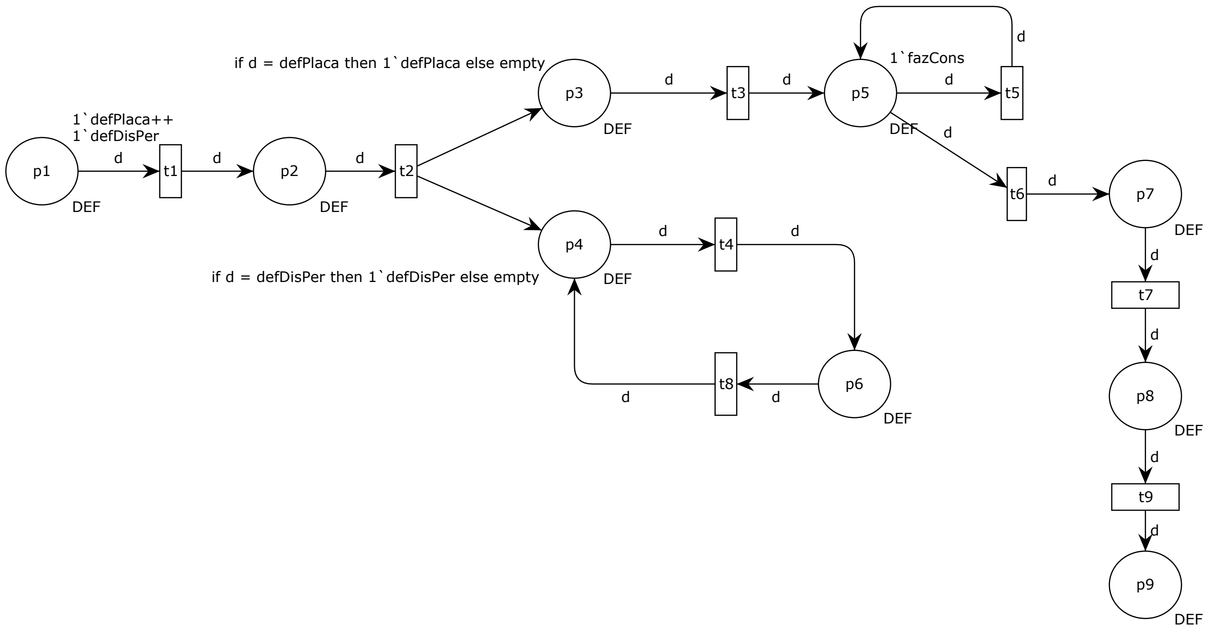

Figure 8: Model in Colored Petri Net of the conical machine corrective maintenance process.

CPN Tools, where several simulation steps were carried out to verify the functioning of the Network. Figure 9 shows the initial state of the CPN, that is, the beginning of the process, in which the records created for the model simulation can be identified. In Figure 10 you can check the operation of the CPN through the displacement of the tokens through the places in the Network, in relation to Figure 9.

Through the proposed RPC model, it was possible to model and simulate the process, focusing on the critical stages of corrective maintenance, and evaluating the use of the technique for this situation. In the presented model, the places and transitions presented in Tables 1 and 2, respectively, are identified.

5.1 Discussion

By analyzing the analysis of the RP model, it is possible to verify that the Network clearly represents the model of the maintenance process and the Network is safe as there is an integer that limits the number of tokens for each place and it is safe as it does not present blockages. These characteristics are positive for maintenance as it means that the process can run without interruptions. Furthermore, all tasks can be executed via an appropriate route, that is, for each task, there is a corresponding state.

In short, the proposed modeling provides maintenance support and directly impacts the performance of the process explored, as it enables, through mathematical formalism, the in-depth analysis of its characteristics, provides an easy-to-understand and safe graphical representation of the process and offers a solution flexible by facilitating modifications and creation of subprocesses.

It can also be said that the model can be represented through a mathematical model as shown in equation (2). The importance of the mathematical model is that any future changes in the modeling can be updated.

6 Conclusion

This work presented the modeling in CPN of a corrective maintenance process of a conical machine in the textile industry. The mathematical model and the PN graph of the model were presented. The main focus of the present work was to propose a model using the Petri Net as a management tool for the corrective maintenance process of a machine in the textile industry. The basis of the proposed model was the application of CPN to model the corrective maintenance process. With the proposed model, it is possible to improve the management of the corrective maintenance process of the machine described here, making the maintenance task fas-

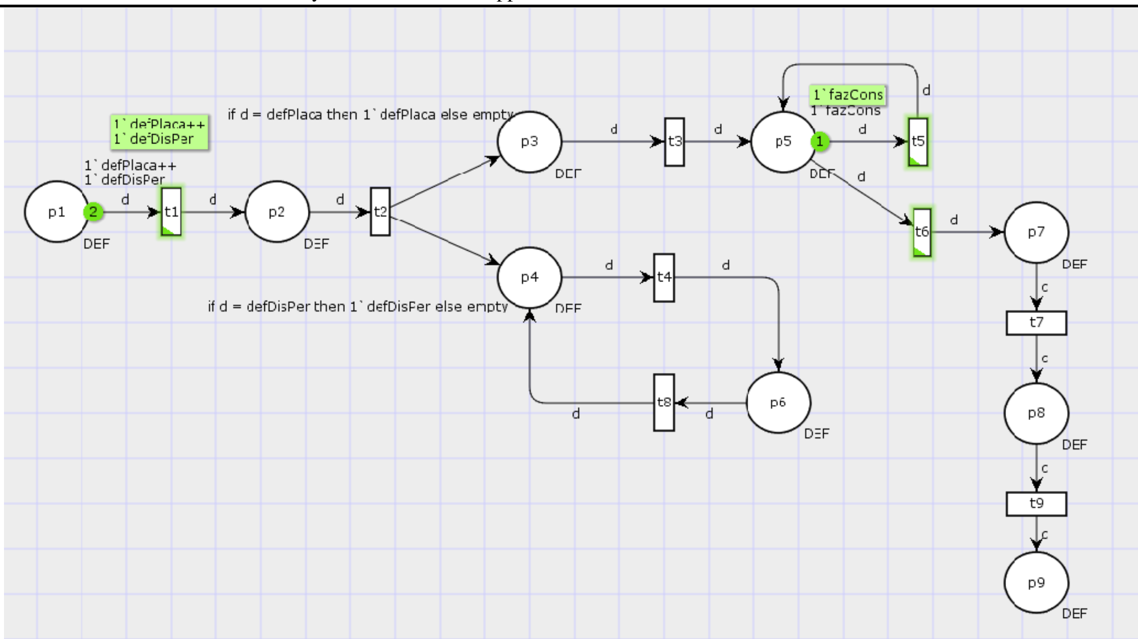

Figure 9: CPN model with the initial state of the conical machine corrective maintenance process.

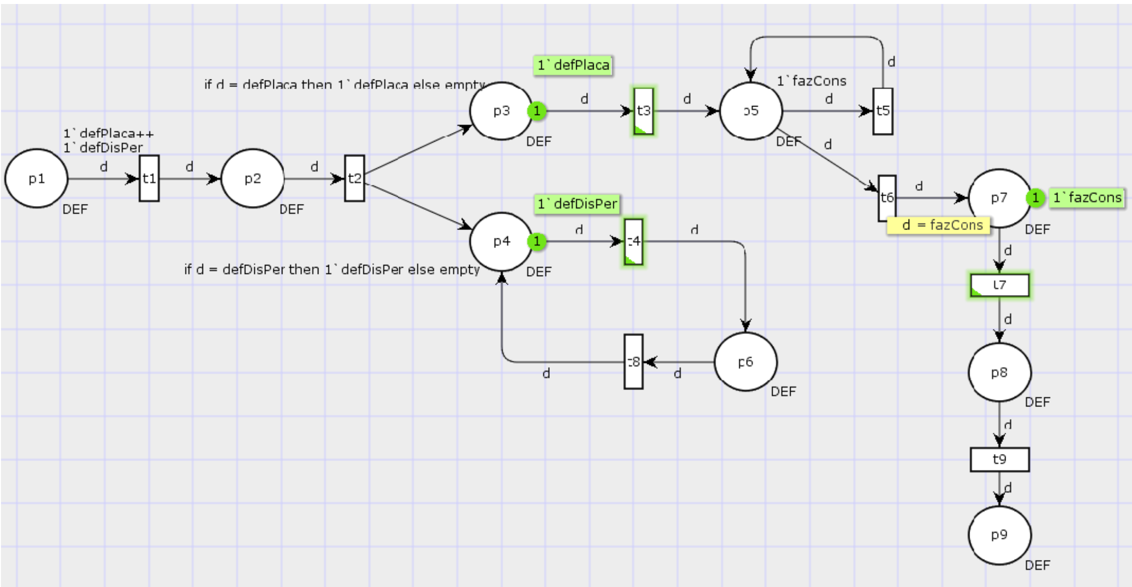

Figure 10: CPN model in operation (simulation) based on the model shown in Figure 9.

ter and saving more resources.

In the analysis of the model, it can also be concluded that from the model it is possible to find critical points in the management of the corrective maintenance task. It is also noteworthy that this modeling was carried out for the corrective maintenance process of only one part of the machine, that is, the electronic part, which can be understood for other parts, such as subnetworks of the modeled network. It can also be concluded that this work presented a qualitative analysis of the corrective maintenance process of the conical machine.

In future works, it is proposed the modeling of the other stages of the maintenance process of the machine and/or other machines, and also, the application of performance evaluation tools with the objective of developing indicators for monitoring the corrective maintenance process.

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