Cylinder Management Flexibilization for Rotogravure Process- Transition for Industry 4.0

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Abstract

Business benefits can be generated from analyzing large amounts of information in real time, reflecting on an efficient way of managing processes. Although not is a reality for most companies, the concepts of Industry 4.0 are already being characterized as a trend for the future. In this way, the purpose of this study was to optimize the delivery time of cylinders for rotogravure print shop process, through the technologies of Industry 4.0. The study was focused on the impacts and the benefits that Industry 4.0 can add to the process. As a method, an observational study was carried out to identify the process reality. After, was developed an adaptation proposal with modeling and simulation for the cylinder management process, based on Industry 4.0 technologies. Was considered only a process in order to not generate complex simulations. The proposed model optimizes resources, bringing satisfactory and immediate results, as well as providing the implantation of this new technology in a gradual way, for the other process steps.

Keywords
Print shop Cylinders, Rotogravure, Simulation, Industry 4.0.

1. Introduction

The constant technological transformation has been changing the competition rules, making that the organizations to take a new look at their processes (Dalenogare et al. 2018). Davis et al. (2015) highlight the change in customer positioning in the last 10 years, the search for customized products and rapid response to market demands has accelerated global competitiveness. In this way, the use of advanced technologies become fundamental in the restructuring of processes (Davis et al. 2015). To invest in a construction of dynamic and autonomous systems capable of remodel processes, and in technologies such as Big Data, Internet of Things (IoT), Cyber-Physical System (CPS) (Bär et al. 2018; Davis et al. 2015), among others, is justified by the storage and exchange of data between these systems along the value chain (Brettel et al. 2014).

Regarded as the fourth industrial revolution, the Industry 4.0, the term originated in Germany, aims to build intelligent products and processes, integrating physical objects with information and communication technologies (TIC) (Brettel et al. 2014; Ciffolilli and Muscio 2018; Dalenogare et al. 2018). The proposal of Industry 4.0 is through connectivity to have more flexible processes and allow the analysis of a large amount of data in real time, creating a series of benefits for industry (Dalenogare et al. 2018). Having noted the importance of technological advancement within manufacturing processes, the three largest producing countries in Europe have launched programs aimed at the development of Industry 4.0, namely: Germany with the programs "High-Tech Strategy 2020", France with the program "*Industrie du Futur*" and Italy with the program "*Piano Nazionale Indústria 4.0*" (Ciffolilli and Muscio 2018; Dalenogare et al. 2018). These programs are aimed at improving processes that benefit the entire value chain, aiming to create a flexible production environment by managing the physical world in a virtual way, adding value to the product/service while maintaining high quality and reducing costs (Ciffolilli and Muscio 2018). However, for this to happen there is a need for prior knowledge of the processes by the organization.

The introduction of Industry 4.0 and its technologies should contribute to a better efficiency of process management. In a rotogravure process, is expected that at the start of the machine setup, the cylinders that will be used, be already arranged as close as possible to start the assembly. In the process under study, the cylinders are stored in a drive-in. For the assembly (next to setup) the cylinders are arranged in supports, with limited capacity. Because of this capability, the transfer of the cylinders from the drive-in to supports and vice versa needs to be optimized and organized in a way that does not waste time (cost for production) during the setup. The problem found in the process is that owing to the large volume of cylinder movements, sometimes waiting times occur, causing costs with stopped machine. With Industry 4.0 technologies, it would be possible to align and optimize cylinder storage, the movements for the supports and production planning in according to the need and assembly times, without any waiting during the setup process. The expected optimization should be focused on creating a flexible production environment through the management of the physical world of virtual form (simulation), adding value to the product and service provided by graphic to the organization. Thus, the objective of this study was to optimize the delivery time of cylinders of a print shop industry, through the mapping of the process and the use of technologies and concepts approached by Industry 4.0. Through mapping and simulation, we sought to define the impacts and benefits that the concepts and technologies of Industry 4.0 can add to the process of storing cylinders. To answer the objective and the research question a systematic review of exploratory literature was carried out followed by the mapping of the current process in the industry.

Process Mapping is a tool that can aid in the identification of activities that lead to wastes (waiting time, rework, unnecessary activities) along the value chain contributing to an improvement in a lead time of the process (Salgado et al. 2009). A visit to the cylinder storage in the print shop industry was necessary to map the process. An interview was conducted with the area manager, with the purpose of seeking more information to complement this study.

Software's of simulation presents key importance in the modeling and simulation of the studied processes, facilitating the visualization of bottlenecks, giving to the research group the option of testing several scenarios quickly and inexpensively. Campos et al. (2017) explored this possibility, using the software Arena®, to redesign internal logistics operations of a factory in order to adapt this process to Industry 4.0. This importance can be contacted by the scope of the areas that use the simulation, such as the provision of services (Melo et al. 2011); development of algorithms for health (Botassoli et al. 2015); teaching (Silva et al. 2007); and logistics (de Oliveira et al. 2017) to simulate different scenarios of reverse logistics. In the present research the software Arena® was used to verify the lead-time considering the current process and the new proposal developed, using emerging technologies.

2. Theoretical background

The importance and key technologies of Industry 4.0 are addressed in order to indicate possible uses for the optimization of the delivery time of cylinders in a print shop industry. This section presents a review about process mapping, Business Process Model and Notation, and cylinders management for print shop rotogravure process.

2.1. Importance and Technologies of Industry 4.0

Industry 4.0 has been discussed for some time theoretically and although it is not a reality in most companies, it is already considered as a trend for the companies of the future. Research in this area indicates that the arrival and deployment of new technologies is the way for industries to reach the "4.0" stage. Many authors are very optimistic in their forecasts. Connectivity and interaction between products, machines, and humans will increase productivity by 30% and become 25% more efficient (Rüßmann et al. 2015).

Companies in countries such as the United States of America, Germany and Japan expect an increase in revenue by 23% and productivity by 26%, as well as a replacement of equipment in the range of 40 to 50% of the factory installed base over the next 10 years, according to with 300 specialists from these industries (Wee et al. 2015). With the implementation of Industry 4.0 technologies, the main manufacturing industries in Flanders, Belgium, expect on average to reduce operating costs by 2.6% per year, while increasing efficiency by 2.4% per year (Vermeire et al. 2017).

Industry 4.0 is characterized by the integration of different cutting-edge technologies (Ghobakhloo 2018). Among the major technological advances of Industry 4.0, the deployment and integration of the Big Data, Cloud Computing, Cyber-Physical Systems (CPS), Internet of Things (IoT), Simulation, Augmented Reality and Additive Manufacturing (Rüßmann et al. 2015).

The Big Data refers to the collection and analysis of large volumes of data from many sources, providing many opportunities to turn current manufacturing into intelligent manufacturing (He and Wang 2018; Tao et al. 2018). Since the volumes of data collected in the industry are growing (Tao et al. 2018), the focus of this technology is intelligent models from real-time data to support decision making (Qi and Tao 2018; Rüßmann et al. 2015; Zheng et al. 2018). This enables organizations to generate economic value by discovering, capturing and analyzing existing data, identifying likely events, and then what actions need to be taken to achieve the best results (LaValle et al. 2011).

On the other hand, computing and cloud manufacturing can be understood from the perspective of a data storage central system, with the support of IoT technology, allows a network of remote communication between products, devices, and machines (Fatorachian and Kazemi 2018). With the growth of collection and sharing of dados in Industry 4.0, manufacturing processes will be data-driven with cloud computing support (Rüßmann et al. 2015). The cloud will direct the control of machines and devices, becoming more flexible, since it can be updated easily (Zheng et al. 2018). This will provide users of information and communication technology a new dimension of resource convenience (Zhan et al. 2015), making access to manufacturing resources easily shared and disseminated comprehensively across factories and globally (Rao and Prasad 2018).

The cyber-physical systems combine statistical techniques, computational modeling, and real-time data extraction from physical systems to model the response of a system under multiple scenarios to make decisions in real-time (Ahuett-Garza and Kurfess 2018; Rao and Prasad 2018). These systems allow communication between machines, humans, and products (Babiceanu and Seker 2016). Cyber-physical systems integrate the physical and digital world, where the physical devices and the physical processes occur, in function to these devices, are digitized, creating digital systems identical to the physical systems (Lu 2017). An important action is a multidisciplinary collaboration between engineers, industrial experts, and computer scientists to accelerate the creation and development of cyber-physical systems, identifying requirements, opportunities and challenges in various sectors (Zhong et al. 2017).

The Internet of Things is characterized by the deployment of sensors and communication devices in physical objects such as machines and manufacturing lines. Through embedded electronics, these physical devices are able to connect to the internet (Kang et al. 2016; Shrouf et al. 2014) and interact with each other and with controller systems, through a network infrastructure (Lu and Cecil 2016). In this way, this technology enables rapid generation and exchange of information, contributing to the improvement of its flow within organizations (Ahuett-Garza and Kurfess 2018; Rao and Prasad 2018). Internet of Things together with cloud computing offers a new level of connectivity for the industrial chain, allowing automatic communication of your needs and manufacturing capabilities (Ghobakhloo 2018), decentralizing analysis and decision making, enabling real-time responsiveness (Hernann et al. 2016; Hofmann and Rüsch 2017; Li et al. 2017). Thus, the connectivity brought by this technology allows for productivity improvements and cost reduction in manufacturing (Kang et al. 2016; Rüßmann et al. 2015).

Already, the simulation builds models of systems or processes, real or not, to understand or better predict their respective behavior, through analog representation, physics or mathematics, among others (Rodič 2017). This technology represents the integration of the physical and digital worlds (Qi and Tao 2018). Simulation and modeling will be required to leverage real-time data to mirror the physical world in a virtual model with machines, products, and humans (Qi and Tao 2018; Rüßmann et al. 2015). This will allow machine configurations to be tested and optimized even before production, increasing productivity and quality (Mosterman and Zander 2016; Rodič 2017). With the support of big data and other communication and information technologies, Industry 4.0 simulations will enable companies to better predict market trends with a more accurate understanding of consumer buying patterns (Ghobakhloo 2018).

With augmented reality it is possible to create a virtual world where operators can learn and interact with machines through digital representations (Rüßmann et al. 2015), combining real and virtual objects in the same environment (Carmigniani et al. 2011). It is a technology that can be applied directly on the factory floor of the industries, allowing the remote involvement of employees in real time with the machines and operations (Kang et al. 2016). This technology is applied for operational data retrieval, conversion of work instructions and also simulations for manufacturing processes (Lee et al. 2011; Rüßmann et al. 2015). In addition, in Industry 4.0, the development of products will include the insertion of augmented reality and the additive manufacture for the construction and interaction of intelligent 3D prototypes (Zheng et al. 2018).

Additive Manufacturing is characterized by the manufacturing technique in which parts or products are constructed by the deposition of layered materials. The layers are built one on top of the other, the plastic is the most common material in this technique. The reference geometry for construction is based on models Computer-Aided Design (Esmaeilian et al. 2016). These additive manufacturing methods will be widely used to produce small batches of custom products that offer advantages in the construction of complex and light designs (Yao and Lin 2016). 3D printing is an example of technology that companies have begun to adapt to build prototypes and produce individual components (Rüßmann et al. 2015).

Another technology, which was already present in the previous industrial "revolution", but which in the future presented by Industry 4.0 will become intelligent, are the robots, which will be called autonomous robots or intelligent robots, and will allow advances in productivity to the companies (Blanchet et al. 2014). Are expected that Robots and humans working side-by-side in the industry, integrating human-machine tasks (Blanchet et al. 2014; Vaidya et al. 2018). Autonomous robots can perform tasks with intelligence and precision, within stipulated times, and yet in a secure, flexible and collaborative way (Rüßmann et al. 2015; Vaidya et al. 2018). Through the incorporation of sensors, artificial intelligence, and other embedded components, the interconnection and communication of robots will be possible (Bibby and Dehe 2018).

2.2. Print Shop Processes

In order to compare the different processes of industrial packaging printing, will be approached as processes of printing: rotogravure, flexography and offset.

The process known as Rotogravure is characterized by a rotary system with low relief matrix, the printing cylinder (Carramillo Neto 1997). The printing takes place directly with the use of liquid paints based on water, and/or solvents (Bohan et al. 2000; Fernandes 2003). The rotogravure has features: color brightness, sharp contrast, high print speed and fast ink drying. However, because it is a high-tech system, the costs are high and the machines are large (Carramillo Neto 1997; Fernandes 2003). Due to the characteristics of the process, it becomes economically viable only for large print volumes (Fernandes 2003). The printing in the rotogravure process is carried out by immersing the matrix cylinder in the Inkwell. When rotated, the cylinder is covered by a layer of ink, which passes through a part called doctor blade, which is responsible for eliminating the excess of ink from the cylinder surface, leaving only the ink inside the alveoli (small "holes" for ink transfer) in the matrix. For the actual printing, the ink that is inside the alveoli is transferred to the substrate (flexible paper or film) through direct contact with the cylinder (Bohan et al. 2000; Fernandes 2003; Macak et al. 2018).

Flexography, also known as an industrial packaging printing process, is considered a high-speed process for various substrates. Printing consists of the process of transfer paint to the substrate through the clichés (flexible rubber sheets). The quality of the cliché is what guarantees the quality, the repeatability of the process and the overall quality of the graphic product (Miljković et al. 2018). Flexography has come about through the search for a low-cost printing process for products where print quality is not a priority (Fernandes 2003). Since flexography is inferior to rotogravure in print sharpness and general quality, for large print volumes, rotogravure becomes viable.

Due to the versatility of the process, offset printing is one of the widely used processes. By this process, the printing is capable of being performed on the most different types of substrates, from plastics and papers to metals and fabrics. The print runs can range from small volumes to large print volumes. The transfer of the matrix image occurs indirectly, requiring a rubber blanket that transfers the image from the matrix to the support and then to the final substrate (Fernandes 2003). In the offset process, there is a fundamental element, the water, which is responsible for repelling the ink in the non-printed areas in the matrix. A problem in this process is the great use of water, because it always seeks the best balance of the system, in which with a smaller amount of water, the perfect absence of paints can be obtained in the non-printed areas in the matrix (Carramillo Neto 1997). A striking feature of the offset process in relation to the others is in the continuous and well-defined forms of the print, and also in the full and spotless colors, delivering a high quality in printing (Fernandes 2003).

2.3.1. Cylinder management in the rotogravure printing process

The cylinder management consists of the form of storage, organization and availability of them for use in the printing process. Once engraved, the cylinders can be used several times, in different batches of production. If there is any wear or physical problem on the cylinder, it should be reengraved.

One of the reasons for the high cost of production by rotogravure is in the engraving of the matrices, which are the metal cylinders with steel core and are coated with copper and chromium (Fernandes 2003; Macak et al. 2018).

Care in handling and storage is extremely important for the proper performance of the cylinder in the machine. Since the cylinder exhibits chromium release (wear) or any type of beating, marks or scratches, when it is used in a machine, it begins to transfer stains and defects to the impression causing material losses.

In the process under study, various care is taken to ensure that the cylinders are in full working order. It is part of the process of management and storage of the cylinders care with the matrices, being necessary several stages in the process for verification, protection and proper handling.

3. Methodology

The method used in the research was classified as exploratory and descriptive, performing a preliminary observational study with the purpose of knowing the reality of the process under study to better adapt the proposal for modeling and simulation of the process of management of cylinders for printing by Rotogravure. A case study for later modeling and simulation was performed, because the case study allows a phenomenon to be studied in relation to its real-life context, constructing a model of reality under study (Miguel 2007; Yin 2003). The case study also allows the use and different methods of collecting quantitative data, such as documented records in the company, observations, interviews, discussions, questionnaires, among others. With the accomplishment of the modeling and the simulation, it is intended to know and register the reality and the wastes existing in the process and, in this way, to model the system using simulation tools, making it explicit for the promotion of improvements. To carry out the case study with modeling and simulation, according to Yin (2003); Miguel (2007); Banks et al. (2005) e Chwif and Medina (2006) the following methodological steps were used in Figure 1.

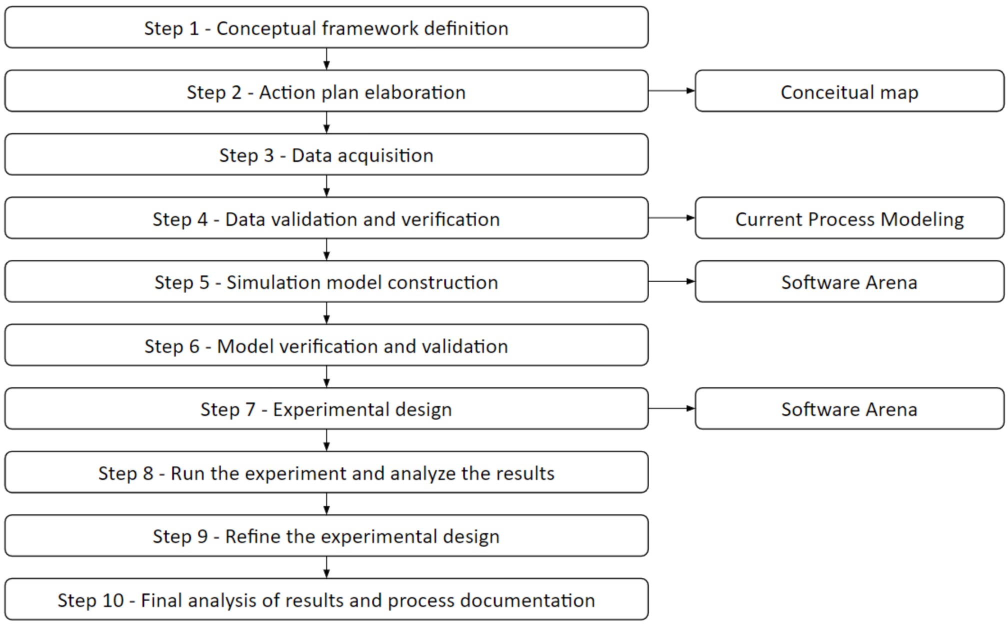

Figure 1. Methodological steps.

Step 1 - Definition of a framework: theoretical and methodological. In this stage, a literature review was carried out to delineate the theoretical-methodological propositions, as well as the real motives that led to the construction of the study and models for the representation of reality.

Step 2 – Elaboration of the plan of action, where we tried to plan the case. A first visit was made to the company to observe the entire rotogravure process, seeking to choose the means of data collection and analysis. From this visit, the development of a first model for the study of data flow was carried out. Initially, a map was developed (Fig. 2) to indicate the actions and paths for the development of this study. Meetings with process agents were conducted to acquire new information and data.

Steps 3 e 4 – Data acquisition and validation: the data to be collected depends on the model created in the previous step. For existing systems, historical data is recommended. Therefore, historical production data were collected over a period of thirty days (see Table 1 - item 4.1). As they are historical data they are validated.

Step 5 – Construction of a model to carry out the simulation study: the model itself was built at this stage and, at this stage, the Arena® software was chosen to perform the simulations.

Step 6 – Verification and validation of the model: in this step, the fidelity relationship of the results obtained with the constructed model and the actual system with the operation data (the historical data of the production) were collected in the company.

Step 7 – Design the experiment: this phase was composed of the tests to analyze and compare the different possible alternatives in the solution of the problem studied.

Step 8 – Run the experiment and analyze the results: here the simulation is executed (see items 4.2 and 4.3). It is important to document the results obtained for each evaluated alternative.

Step 9 – Refine the experiment design: if the results are not satisfactory repeat the procedures from step 7, which was not necessary.

Step 10 – Final analysis of the results and process documentation: finally, with adequate data reliability and consistency of results, the final documentation is performed. In this stage, of analysis of the results it is important to add values referring to the study carried out, being possible, to measure the gains of the work.

4. Results and discussions

Figure 2 is a map that represents a model of reality in study, where can be observed the relations between components, information flow within the system, and hierarchy of its modules were considered in this step.

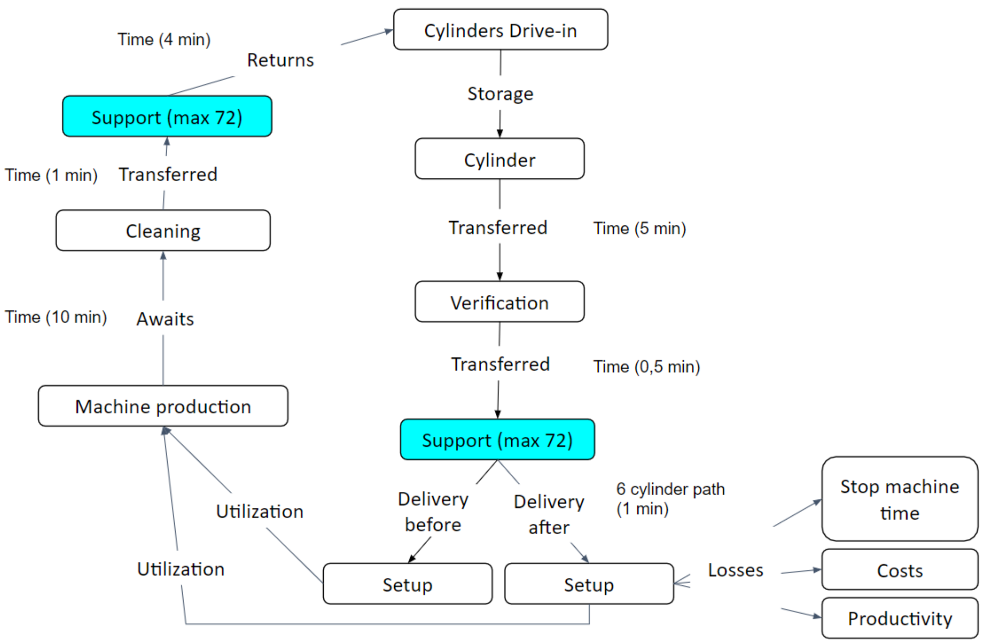

Figure 2. Model of reality in study.

The information described in Figure 2 were the results of the visit and observation of the rotogravure process from the cylinder drive-in. The map was created in agreement with the agents of the process.

4.1. Analysis of the current process

In the current scenario of the storage and delivery of cylinders, the following activities and mode of operation are observed:

From the cylinder drive-in, a storage place composed of more than 1500 places, where the cylinders are available in case of necessity of using them. Depending on production planning, it is necessary for the item set of cylinders to be removed from the drive-in and available to the assembly area (area belonging to the production process). By an internal definition of good working practices, in order to allow them to be assembled before the start of the set-up, the set of cylinders must be delivered within two hours before.

The production process is composed of two machines, both of which uses cylinders of the same size, with a production queue for each one. The rules for delivering cylinders are equally valid for the both machines, which operate in parallel. Once the cylinders have been delivered, they are assembled, used in one or the other machine, then washed and returned to the cylinder drive-in (according to the map already presented in Figure 2).

The assembling area has 12 supports (cages) with places for six cylinders each. As an example, in the case of an item consisting of an 8-cylinders set, it needs to use a full support and 2 additional places in other support. The process operators "fill" the supports according to the production queue, always respecting the previous time of need of the cylinders in the assembly area. It is worth mentioning that the supports are used for cylinders of both machines and that the cylinders, already used in the machine, also occupy the same supports, until they are stored in the drive-in. In table 1, an example of the production planning of a month of the study of a machine is shown, as well as the number of cylinders per item and the times of start and final of machine production.

Table 1. Production planning.

Nov/2018 - Machine #1							
Production type	**Used Cylinders**	**Start Date**	**Final Date**	**Production type**	**Used Cylinders**	**Start Date**	**Final Date**
A	8	01/nov - 01:50 hs	01/nov - 12:00 hs	B	4	19/nov - 11:30 hs	19/nov - 15:34 hs
A	8	01/nov - 12:00 hs	01/nov - 23:45 hs	B	4	19/nov - 11:30 hs	19/nov - 13:00 hs
A	8	01/nov - 23:45 hs	05/nov - 12:40 hs	B	4	19/nov - 13:00 hs	19/nov - 17:15 hs
A	8	05/nov - 12:40 hs	05/nov - 18:40 hs	A	8	19/nov - 17:15 hs	20/nov - 22:30 hs
A	8	05/nov - 18:40 hs	05/nov - 22:40 hs	A	8	20/nov - 22:30 hs	22/nov - 00:30 hs
A	8	05/nov - 22:40 hs	06/nov - 05:00 hs	A	8	22/nov - 00:30 hs	22/nov - 15:35 hs
A	8	06/nov - 05:00 hs	07/nov - 08:50 hs	A	8	22/nov - 15:35 hs	22/nov - 22:00 hs
A	8	07/nov - 08:50 hs	07/nov - 18:50 hs	A	8	22/nov - 22:00 hs	23/nov - 06:00 hs
B	4	07/nov - 18:50 hs	08/nov - 01:00 hs	A	8	23/nov - 06:00 hs	23/nov - 17:50 hs
B	4	08/nov - 01:00 hs	08/nov - 08:50 hs	A	8	23/nov - 17:50 hs	23/nov - 23:30 hs
B	4	08/nov - 08:50 hs	08/nov - 11:15 hs	A	8	23/nov - 23:30 hs	26/nov - 04:00 hs
B	4	08/nov - 11:15 hs	08/nov - 11:45 hs	A	8	26/nov - 04:00 hs	26/nov - 08:55 hs
B	4	08/nov - 11:45 hs	08/nov - 14:00 hs	A	8	26/nov - 08:55 hs	27/nov - 01:15 hs
B	4	08/nov - 14:00 hs	08/nov - 15:40 hs	A	8	27/nov - 01:15 hs	27/nov - 06:00 hs
A	8	08/nov - 15:40 hs	09/nov - 22:00 hs	B	4	27/nov - 06:00 hs	27/nov - 08:50 hs
A	8	09/nov - 22:00 hs	10/nov - 00:15 hs	A	8	27/nov - 08:50 hs	27/nov - 20:40 hs
A	8	10/nov - 00:15 hs	12/nov - 09:30 hs	A	8	27/nov - 20:40 hs	28/nov - 01:00 hs
A	8	12/nov - 09:30 hs	12/nov - 14:20 hs	B	4	28/nov - 01:00 hs	28/nov - 05:30 hs
A	8	12/nov - 14:20 hs	12/nov - 21:35 hs	B	4	28/nov - 05:30 hs	28/nov - 08:30 hs
A	8	12/nov - 21:35 hs	13/nov - 04:30 hs	B	4	28/nov - 08:30 hs	28/nov - 12:15 hs
A	8	13/nov - 04:30 hs	14/nov - 03:10 hs	B	4	28/nov - 12:15 hs	28/nov - 16:00 hs
A	8	14/nov - 03:10 hs	16/nov - 22:00 hs	A	8	28/nov - 16:00 hs	29/nov - 00:55 hs
A	8	16/nov - 22:00 hs	17/nov - 06:25 hs	A	8	29/nov - 00:55 hs	29/nov - 15:05 hs
A	8	17/nov - 06:25 hs	17/nov - 12:40 hs	A	8	29/nov - 15:05 hs	30/nov - 07:10 hs
B	4	17/nov - 12:40 hs	17/nov - 13:00 hs	A	8	30/nov - 07:10 hs	30/nov - 13:05 hs
A	8	17/nov - 13:00 hs	17/nov - 18:00 hs	A	8	30/nov - 13:05 hs	30/nov - 22:00 hs
B	4	19/nov - 06:00 hs	19/nov - 11:30 hs				

It is also added that the process of storage and delivery of cylinders is operated in single shift, 8 hours and a half, and the movement of the supports is done by an operator. The data observed and raised in this analysis of the current process are the bases of times, quantities and processes used in the scenario simulations.

4.2. Simulation of scenarios

In the simulations carried out, the first simulated scenario was the mapping of the current process (Fig. 3), with the purpose of observing the real times. After analyzing these data, will be possible to compare with the proposed model and to observe if there were significant gains in relation to the previous process.

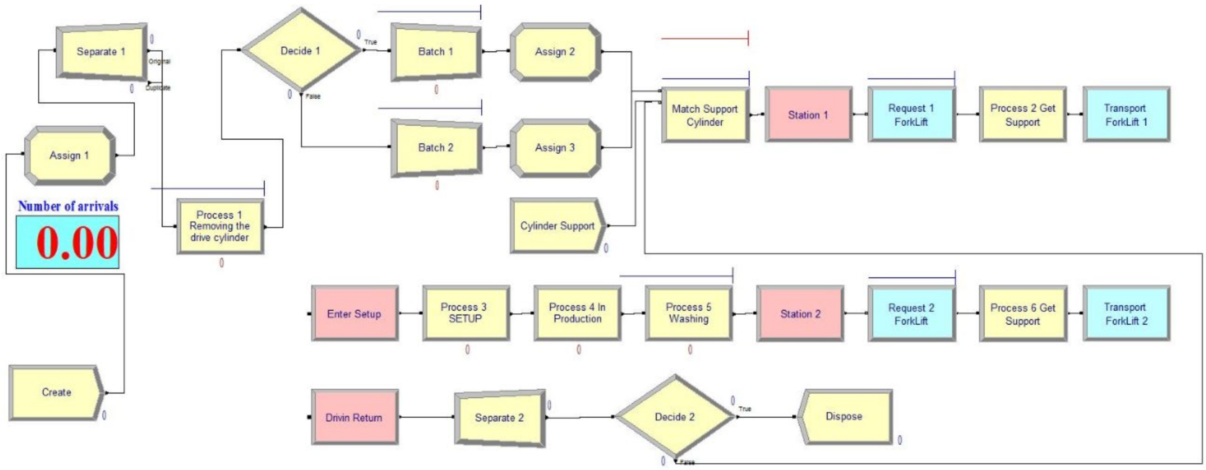

Figure 3. Current process modeling.

In the configuration presented in (Fig. 3), current process, the beginning happens with the arrival of the requests (Create), passing through the module (Assign 1), necessary to be assigned the quantity of cylinders to the request. In the sequence, (Separate 1) the order is separated in the number of cylinders assigned. In the first process (Process 1) the removal of the cylinders from the drive-in takes place and goes to (Decide 1), where through the main exit pass six cylinders, which is the capacity of the support in which they will be taken to the place of the setup. Then, go to (Batch 1) where they group to join the support in (Match 1) and wait for the forklift in (Request 1). In the same way, the cylinders that pass to the secondary output of (Separate 1) are grouped in (Batch 2), regardless of the quantity. Then, at the point where the cylinders are placed in the supports (Match 1), it was where the bottleneck of the system was found. In the simulation performed, the time of the cylinders in the queue waiting for the supports was 864.4 and 31.9 min, of the cylinders coming from Batch 1 and 2, respectively. This time refers to the simulation of seven days, 24 hours a day, ten repetitions. In the report of the employees of the company, they also point out the lack of supports as the crux of the process, because of the limited amount of supports, besides the inadequate configuration of the same, since they have capacity for only six cylinders of the eight needed for a setup. Carried by forklift, the cylinders must be available two hours before the scheduled time for the setup (Process 3). The sets of cylinders used that leave the printer occupy the same supports that brought the cylinders that went into production (*Process 4*).

The already used cylinders are used for washing (Process 5). After washing, wait for the forklift to return to the drive-in, when they arrive they are removed from the stand (Separate 2) and in (Decide 2) the cylinders return to the drive-in. Finally, the media will return to the process by entering it again (Match 1).

4.3. Proposed future process

After identifying the bottleneck of the process studied, a solution based on Industry 4.0 was searched, so that it was possible to solve the current problem with the concepts of this technology. Without having to apply it to the whole printing process, which would require a high investment. In this way, the implantation of Industry 4.0 could occur gradually in the process of storing and disposing of printing cylinders, as well as in any process that is divided into stages recognized by the mapping performed (Fig 3).

Starting from the idea of initially solving the current bottleneck, the suggestion of future process was modeled according to the scheme (Fig. 4). In which it differs from the current scheme presented in (Fig. 3), by the substitution of the support, transported by forklifts, by autonomous robots (technology identified of Industry 4.0) with capacity to transport eight cylinders at a time. These robots can use more joint technologies, such as Big Data, IoT and Cloud computing, to store information and perform communication in the environment in which they are inserted. The main difference in the suggested process was due to the suppression of the steps of (Batch 1 and 2) where the cylinders are grouped in six units that join the support in (Match 1) that also became unnecessary. The forklift and the twelve supports were replaced by three autonomous robots that carry the cylinders from the drive-in to the setup area, which became Process 2.

Remaining the initial simulation, in the same conditions - seven days of production, 24 hours a day, ten repetitions - but with the new configuration suggested, the average occupancy rate of each robot was 39.2% and there was no queue. This makes it possible to affirm with that, even if there is a sporadic increase in the arrival of orders, the idle capacity of about 60% in the robots guarantees that there will be no stops in the process due to the lack of cylinders in time for the setup.

Thus, modeling and simulation of the process using industry technologies 4.0 can be presented as described in Figure 4.

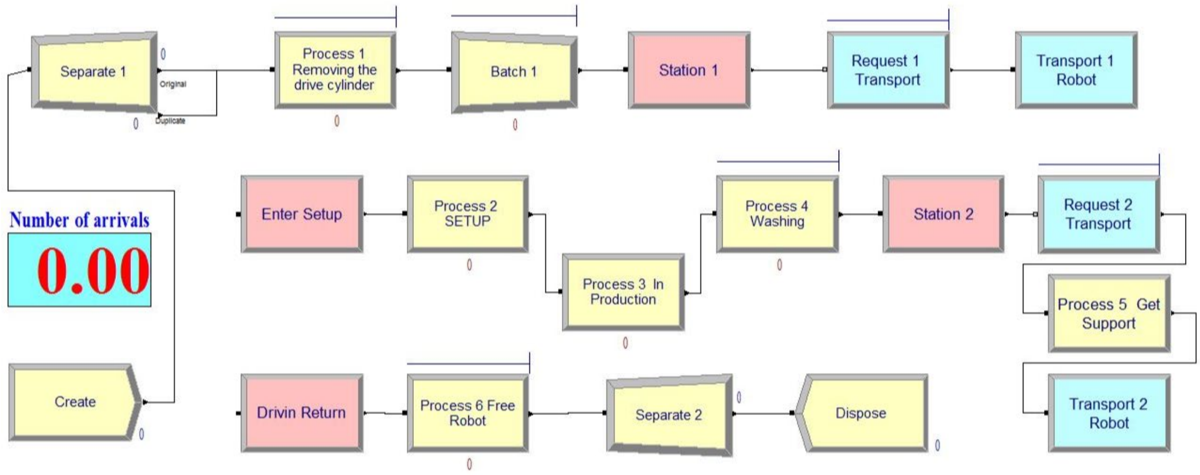

Figure 4. Modeling of the proposed process.

4.4. Final discussion

In the simulation of the current scenario, as presented previously in item 4.2, queues are formed waiting for supports that together reach approximately 896 minutes. Divided by the seven days of the simulation, reach 128 minutes per day. As the estimated wait time for the setup of the support/cylinder set is two hours, this time is dissolved throughout the day. However, this does not mean that there are no sporadic delays due to the lack of sets available, as the number of setups is variable, depending on the arrival of the requests, that is, in days with more cylinder changes the chance of delays due to lack of cage increases considerably.

With the proposed model, the supports are eliminated, which are replaced by robots that also replace the use of forklifts as well as the operator of the same that can assume other functions within the organization. Therefore, the optimization of resources presented in the proposed model, using robots, based on the technologies of industry 4.0, brings immediate gains, such as the end of the queues of cylinders waiting for supports, besides giving the process the possibility of implantation of these new technologies gradually.

Then, from the moment that an improvement is made in a part of the process, with technologies of Industry 4.0, the possibility is opened that the transition takes place progressively. Thus, the investments needed to transform an outdated process can be done in a less concentrated way, investing first in the critical point and, as the new bottlenecks are identified, these are solved with this technology until all stages of the process reach the concept of Industry 4.0.

5. Final considerations

The proposed solution to improve the process is based on two pillars of Industry 4.0, autonomous robots and simulation. Based on the assumptions of earnings indicated in the literature, the proposed model evidenced the benefits of using Industry 4.0 technologies within the management of cylinders for rotogravure printing. The process mapping was shown to be essential to identify all the activities that must be dealt with in the transformation process. Thus, it is possible to identify the impact of the implementation of Industry 4.0 technologies more comprehensively and not only on a specific activity. In addition, the simulation has helped significantly in determining which are the key processes to initiate the implementation of the technologies of the industry 4.0 and consequently in the transformation of the industrial chain. This study points out the mapping of integrated processes to simulation as an essential tool to initiate the analyzes of the digital transformation of the industries. In this way, the proposed method of process mapping and simulation can help the industries in identifying the priority processes to start the implementation of the Industry 4.0. Since the improvement of critical processes is pointed out with great potential for increases in productivity and efficiency in the industry, the use of intelligent manufacturing technologies should be directed towards these processes in order to maximize the benefits.

5.1. Considerations for future work

In order to continue the gradual transformation of the process to Industry 4.0, it is suggested that, after the application of the presented suggestion, a new mapping and simulation of the print shop process. In this way, it is possible to continue identifying new bottlenecks in other stages of the process and to apply new technologies, leading to the progressive change towards digital transformation. Another suggestion is to carry out the same analysis done in the process based on costs and benefits, to then determine if it is in keeping with the current reality of the costs of the technologies.

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