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Business Process Management: A Case Study of Industrial Robotic Arms

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Abstract: In the modern competitive era, the viability of a business depends on its flexibility and its ability to adapt to any circumstance. One way of achieving this is through modeling and management of the business processes in use. Business Process Management (BPM) is a systematic approach for making organization’s processes more efficient and dynamic in order to meet the changing needs of businesses. This paper provides a review on BPM and modeling. Through the study of industrial robots and particularly, the industrial robotic arms, we better understand how business processes are modeled and how this method facilitates the identification and optimization of the current processes. The modeling of the processes was carried out using the Business Process Management and Notation 2.0 (BPMN 2.0) methodology. More specifically, the overall operation of a robotic arm was captured, while complex sub-process and the servo motor operation, which is the driving force of the industrial applications, were analyzed in depth. The Bizagi Modeler tool was used to visualize the processes of the industrial robotic arms.

Keywords: BPM, Business Process Modeling, BPMN 2.0, Robotic Process Automation, Industrial Robotic Arms

I. INTRODUCTION

Nowadays, every business needs to review its structure and behavior in order to support evolving and adapting to a dynamic, ever-changing environment. The need for change has always been important, but today this need is imperative [1].

For most organizations the change is problematic and big changes may be even more difficult. Hence, the business world relies on a new generation of management systems and methodologies of continuous improvement based on flexibility, cost-effectiveness and efficiency, such as BPM. BPM is called upon to address challenges, like the involvement of human resources in change, the commitment of management to adhere to change and the change of mentality of an organization from functional to process-oriented [2]. To assist BPM, a set of software tools has been developed one of which is BPMN 2.0.

This paper is divided into two parts. The first part provides a review of business processes, business process management and modeling, giving special importance to the basic elements of the BPMN 2.0 standard. It is essentially an introduction before the analysis of the case study begins. And, in the second part an attempt is made to apply BPMN 2.0 graphical representation by studying a case study of industrial robotic arms in a general frame. Thus, three diagrams have been created, so as to display the overall operation of a robotic arm; from the moment it is activated until the moment when the wrist of the robotic arm performs the required function.

II. BACKGROUND

Organizations now live in a highly competitive environment. Versatility is no longer the key for the success, but the minimum skill required by a business in order to survive. There is an urgent need to respond to rapid changes of the environment and the only thing that gives now this superiority is the competitive advantage and innovation. BPM comes to satisfy this need. It is a natural and integrated approach of managing the operation of a business, which produces a highly efficient, flexible, innovative and adaptive organization, which is far superior to a traditional approach [3].

In general, the target of businesses and their processes is centralized to the customer. For many years the goal was to develop methods and policies that will overcome obstacles and bridge the business with the customer. Now, more or less, this is taken for granted. The big issue for businesses, this moment, is the pace of change [4]. A business must constantly innovate responding to change, so as to add value to the customer and the market. To do this, the business must have perfectly structured business processes.

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A. Business Process

Successful is the business that achieves its business goals. In order to achieve this, an effective and efficient cooperation of its resources is required. The business process is a very important concept that facilitates this cooperation. We can define a business process as a coordinated chain of activities designed to produce a business result [5]. It can be broken down into several sub-processes, which, although having their own properties, contribute to the achievement of the central process goal. Therefore, a process must involve clearly defined inputs and outputs and to be less complex.

The recipient of the result of a process is the customer to whom must give value. Processes can be categorized into three types depending on the nature of business processes [6]:

- Core processes: are the activities that bring direct value to the company and the customers, such as the manufacturing of a product
- Supporting processes: are all processes whose sole purpose is to ensure the functioning of the core processes, such as the technical support
- Management processes: their main tasks are to measure, monitor and control all the business-related processes and systems

Every business contains business processes that may relate to its internal environment or participate in business processes that relate to its external environment or other businesses [7] [8]. In any case, the processes have to do with the cooperation, the coordination and synergy of its members. The whole analysis and implementation of the processes are described by the term Business Process Management (BPM).

B. Business Process Management (BPM)

BPM refers to the set of actions required to analyze, plan, redesign, implement, execute, optimize and terminate processes that govern the operation of a business. Its goal is the best possible adaption of the company to the requirements of its environment, internal and external [7] [8] in order to increase the efficiency and effectiveness through improvement and innovation [9]. If we used the term in a metaphorical sense, we could say that it is a cookbook, which gives us the recipe for a successful result.

The benefits that an organization has from BPM are [10] [11] [12]:
- Flexibility and adaptability
- Homogenization of processes
- Detection of bottlenecks in the execution of processes, which reduce the overall efficiency
- Faster processing of processes and improved customer service time leading to greater customer satisfaction
- Increased productivity and reduced costs
- Minimizing errors and omissions through structured and automated workflows

BPM systems have now integrated analysis and optimization tools, such as UML, Data Flow, IDEF, Role Activity diagrams, Petri Nets graphs, Gantt charts and Flowchart techniques (BPMN 2.0), in order to enhance process efficiency [13]. Furthermore, some of them use data mining methodologies and analyze real-time historical data, through event logs for example. In these systems, it is common to use Key Performance Indicators (KPIs), which are measurable indicators that usually reflect an organization’s business objectives [10] [5].

Business process models are measured based on KPIs to monitor their performance. Their performance is evaluated by the business objectives and in case they deviate with a difference, which is usually predetermined, decisions are required that lead to the redesign of the business process model. For example some KPIs that is important for the performance of the industrial robotics arms, which will be analyzed in the paper, are the actuation latency, the energy consumption and the CPU utilization. The first KPI is refers to how long it takes from the moment it receives a new signal until the manipulator actually starts moving for the completion of the new task, the second KPI represents an estimation of the total amount of servo motors power consumption of the manipulator and lastly, the third one represents the sum of work handled by the CPU of the PLC [14].

Since business processes aim to simulate business operations and integrate business logic into strictly defined structures, it is a natural consequence that their management should be defined in such a way that it can perform the task of controlling and their analysis. This analysis plays an important role in the management of business processes at various stages during their life, so that the operation of each stage and its importance to be obvious.

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C. Lifecycle of BPM

The BPM lifecycle is the cornerstone of the BPM discipline. It provides a roadmap to systematically and continually improving of business processes. The BPM lifecycle is consisted of six phases, as shown in figure 1 [15] [16] [17].

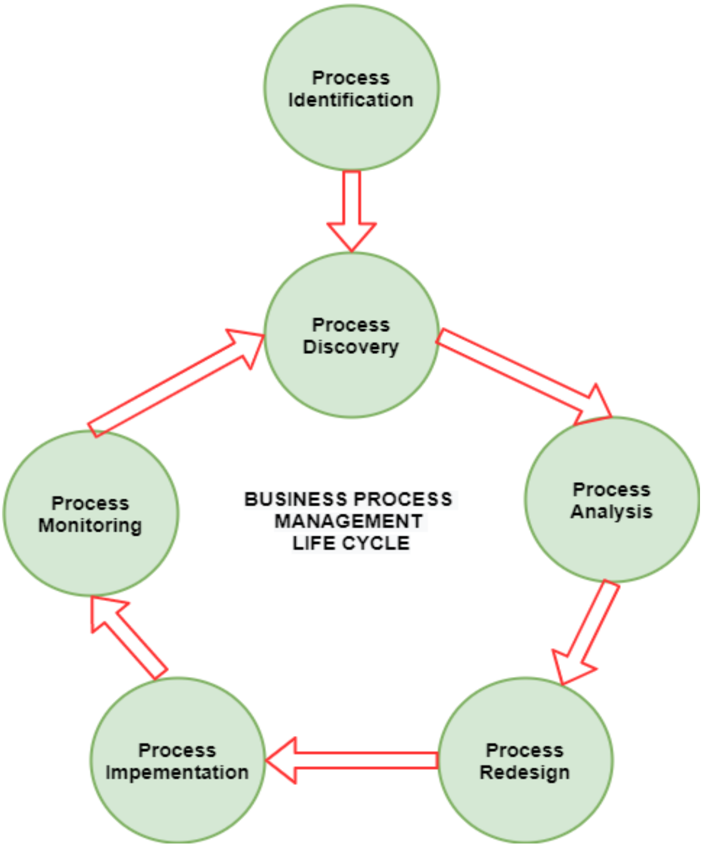

Fig. 1 BPM lifecycle, Source: [15]

The cycle starts with the process identification phase, during which the business processes of the organization are enumerated and prioritized. At this stage, the processes are identified and the relationship between them is defined. The process architecture is obtained as the output of the identification phase, which is a well-organized inventory of the business processes in the organization.

The second phase in the BPM cycle is called process discovery. In this phase, the processes are discovered, decorticated and captured them in a form of a so-called process model [15] [16] [17]. The outcome of process discovery will be a so-called *as-is* business process model. It is called *as-is* because no new ideas are introduced on how to improve the process and depict it in the business process model. The current picture of the process, as it stands, is captured.

The third phase is the process analysis. In this phase the *as-is* process model is taken from the previous phase and along with associated documentation, which is gathered during the discovery phase, are used together in such a way to detect and quantify weaknesses, which are called *issues*.

There are different types of analysis techniques that lead us to different outputs. Some techniques are qualitative and they lead to organized sets of *issues* and factors underpinning these *issues*, like *root-cause* analysis. Root-cause analysis is a method for analyzing the root causes of a problem. It seeks to identify the origin of a problem using a specific set of steps by asking “why” every time [18]. For instance, if a robotic arm stops moving in mid of operation then, we start asking “why” until we get to the root of the problem as shown in the below image.

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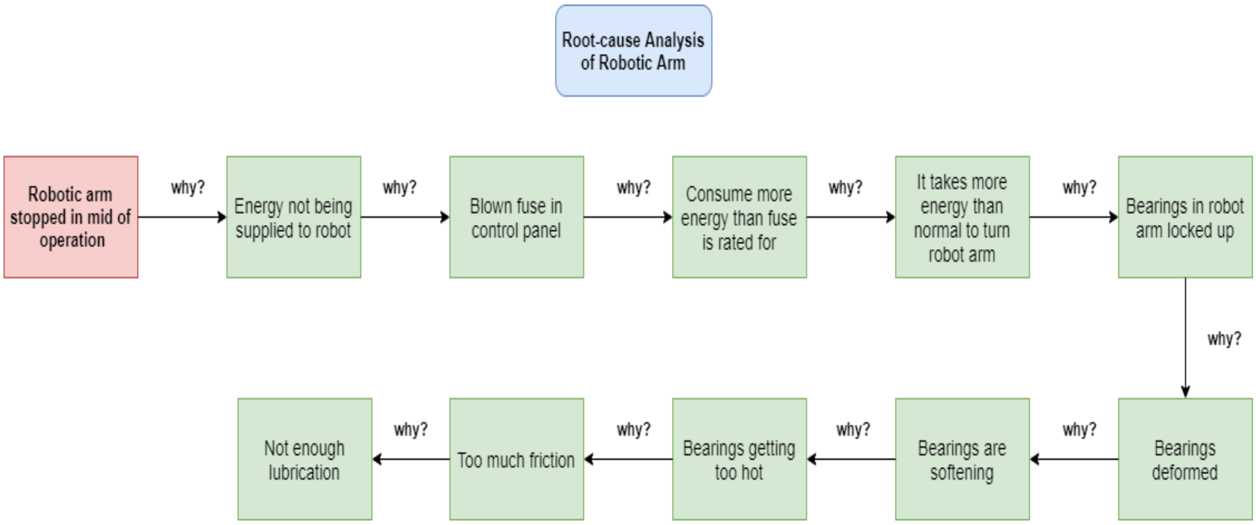

Fig. 2 Root-cause analysis of industrial robotic arm

With this method, in case the same problem occurs again in the future, it will be dealt faster and methodically. Another family of process analysis techniques is more quantitative in nature. For example, process simulation is such a technique that measures the performance of the process in detail under different scenarios. The output of process simulation and related techniques will be a set of dashboards and statistics regarding the performance of the process [15] [16] [17].

The following phase is the process redesign phase. The goal here is to take the *as-is* model and the insights and weaknesses that we identified in the previous phase, and to come up with a *to-be* process model. Redesign is about making a trade-off between different performance attributes, four of which are the cost, the time, the quality and flexibility. Redesign is trying to improve one of these attributes without affecting too much the others.

The fifth phase is the process implementation. In this phase the process is executed and involves at least two set of activities. The first aspect is the automation activity, which is concerned on the use of the workflow systems that are going to support the participants in the performance of the process. And the second aspect of process implementation is the organizational change management around the process change [15] [16] [17].

The last phase in the BPM lifecycle is the process monitoring. This stage is responsible for continuously monitoring the conformance and performance of the process and whether the changes that are made in the previous phase, had the expected results [15] [16] [17]. If conformance and performance are not according to the desired outcome, then the cycle is repeated.

D. Business Process Modeling

Modeling is a key tool for understanding, designing and improving a business [19]. The goal of modeling the processes of an organization is not to model the whole organization in detail, but the analysis and modeling of those processes, whose execution and control could be automated or even improved.

Business modeling could be defined as a collection of techniques and tools designed to capture the behavior of business systems in terms of processes [10]. Stakeholders in this process, such as the organization executives, system analysts and programmers, use business models to address the complex and dynamic nature of modern organizations. These models support the design (or redesign) and the continuous improvement of the process. Therefore, the modeling of business processes is a continuous activity and not an activity with a predetermined end.

A number of tools have been developed for the operation of modeling and methodologies, which aim to help and automate the modeling operation. The most common tool is the Business Process Model Notation 2.0 (BPMN 2.0), as it can be easily read by someone, who has no experience in business process modeling and can model various types of processes [20]. The advantages of process modeling are summarized below [11]:

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- Optimizes the adoption of organizational changes
- Facilitates the understanding of the process by each participant
- Accurately determines the time and the cost of performing the procedures
- Provides the ability to simulate a process
- Improves the decision-making mechanism
- Captures business knowledge with predefined models

E. Business Process Model Notation 2.0 (BPMN 2.0)

BPMN is a standard for modeling business processes [21]. Its main purpose is the creation of a method of representation, which will be easily recognizable and understandable by the whole business world. At the same time, it should be possible to depict complex business processes and, through its diagrams (BPDs – Business Process Diagrams), to provide a visualized presentation of business processes, instantly convertible to executable language BPEL (Business Process Execution Language) [22].

BPMN 2.0 is the latest version of this BPMN standard, developed by the Object Management Group with the aim of producing a unified modeling language that is understandable to all business users. It bridges the gap between business process design and implementation. This simplifies the user task by setting out a clear software diagram.

To achieve the dual goal of simplicity and strong implementation, in order to meet the complex business scenarios, BPMN organizes its graphic objects in various categories [23]. The four main categories are:

- *Flow Objects*: events, tasks, sub-process, gateways
- *Connecting Objects*: sequence flow, message flow, association
- *Swimlanes*: pool, lane
- *Artifacts*: data object, group, annotation

Initially, the flow objects are the graphs that determine the behavior of a business process. While, the events are something that happens during a business process and there are three types of them (start, intermediate, end), based on when they affect the flow. In addition, the task represents an activity that company performs. If these activities are compound, then they called *sub-process*. A gateway is used to control the divergence and convergence of the flow [23] [24].

Secondly, the connecting objects connect the flow objects to each other or to others sources of information. Sequence flow connects flow objects in proper sequential order and message flow represents messages from one process participant to another. Association shows relationships between artifacts and flow objects [23] [24].

Thirdly, the swimlanes are elements that allow distinguishing participants and responsibilities in a business process diagram. This makes it possible to organize the diagram in activities in order to display different functional capabilities or roles. Pool represents a participant in business collaboration and act as a container. Lane is a sub-partition within a pool. Lanes are used for allocating activities to roles, systems or the organization's departments [23] [24].

Lastly, the artifact represents information relevant to the model but not to individual elements within the process. Data objects represent the data placed into the process, data that resulting from the process, data that needs to be collected, or data that must be stored.

Group organizes tasks or processes which have significance in the overall process. Annotation is a mechanism for a modeler to provide additional information for the reader of the BPMN 2.0 diagram [23] [24].

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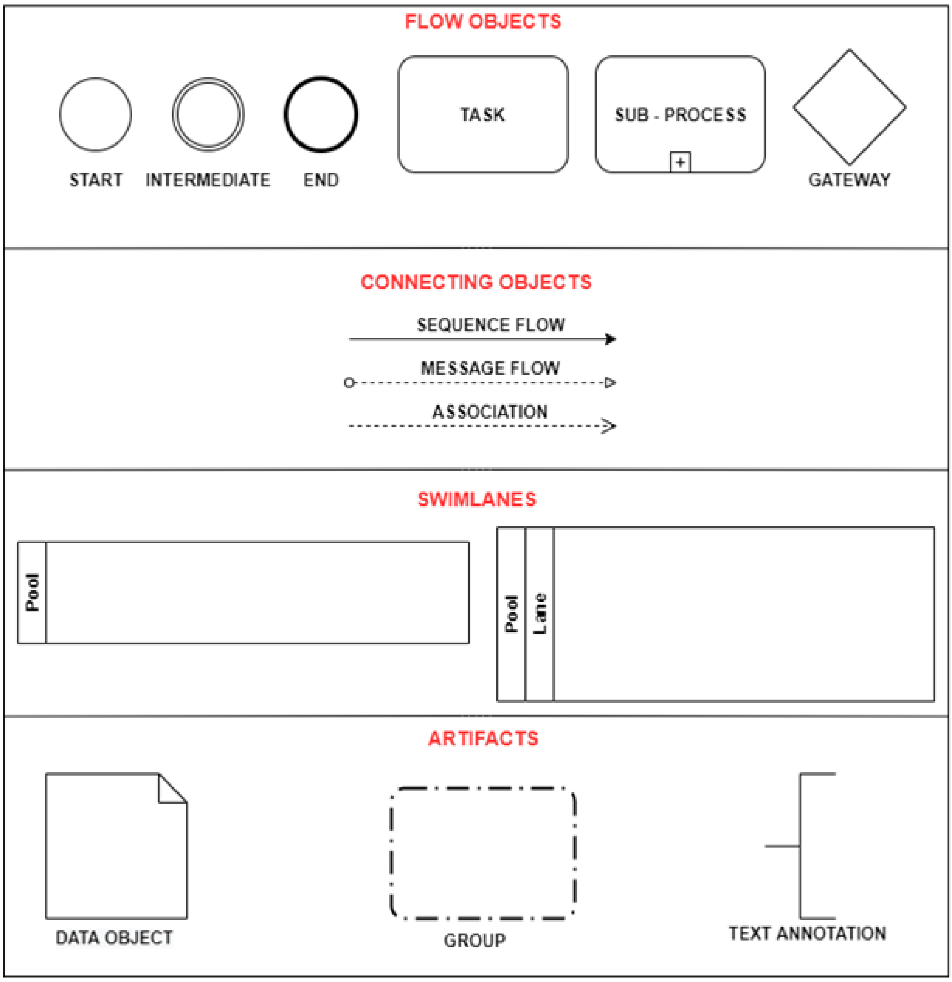

Fig. 3 Basic Elements of BPMN 2.0, Source: [23]

III. CASE STUDY

A. The Importance of Robotic Process Automation (RPA)

The advent of Robotic Process Automation (RPA) was a key milestone for the development of the industry. Nowadays, businesses focus significantly in the RPA, which is programmed, trigger-based automation to handle structured data and standardized processes [25]. It automates repetitive tasks and replaces the human intervention to streamline and speed-up the business processes [25] [26]. Consequently, RPA introduces several advantages, some of which are the reduction of labor cost as well as the avoidance of human error.

If an organization manages to integrate RPA to BPM, then it will have maximum efficiency as BPM provides in-depth process knowledge that is required for RPA process identification and implementation [26]. With the integration of RPA to BPM techniques, the scope of RPA will be broadening in order to execute business processes in an organizational level [26]. RPA techniques are widely used in industry and especially in industrial robotic arms.

B. Industrial Robotic Arms

A robotic arm is an electro-mechanical mechanism that mimics the movements of the human hand. It consists of links and joints. In correspondence with the human hand, the links correspond to the bones (clavicle-scapula, humerus and ulna-radius) and the joints in the human joints that join the bones (shoulder, elbow and wrist joints) [27]. It is worth mentioning that the wrist joint consists of a set of mechanical joints that allow rotation around three axes, the longitudinal, the transverse and the vertical [28]. The longitudinal is responsible for the direction of the fingers (roll), the transverse is at the level of the palm (pitch) and is perpendicular to the fingers and the vertical is perpendicular to the other two (yaw) as shown in figure 4.

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For the implementation of the joints of a robotic arm, various types of mechanical joints are utilized. The main types of the mechanical joints are rotary, linear and spherical [29]. The former implement a relative rotational motion between two successive links, the second ones implement a relative translative motion and the latter implement a relative spherical motion between two successive links.

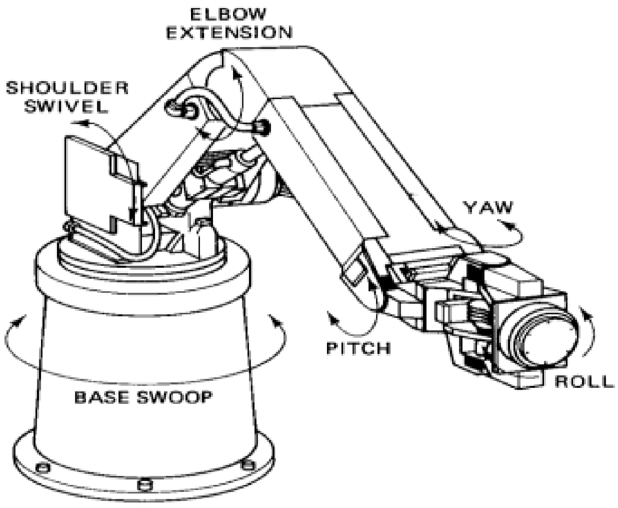

Fig. 4 Parts of Robotic Arm, Source: [30]

What mainly characterizes a robotic arm is its freedom of movements (Degrees of Freedom-DOF) [31] [32]. For example, a robotic arm that moves in a two-dimensional space has less capability than one that moves in three-dimensional space. Usually, at the end of the wrist of the robotic arm, a tool is placed with the help of which a task will be performed (end effector). If it can be placed anywhere in the space and with any direction, then we say that it has six degrees of freedom, three for its position in the space (XYZ) and three for the orientation of the tool as shown in figure 5.

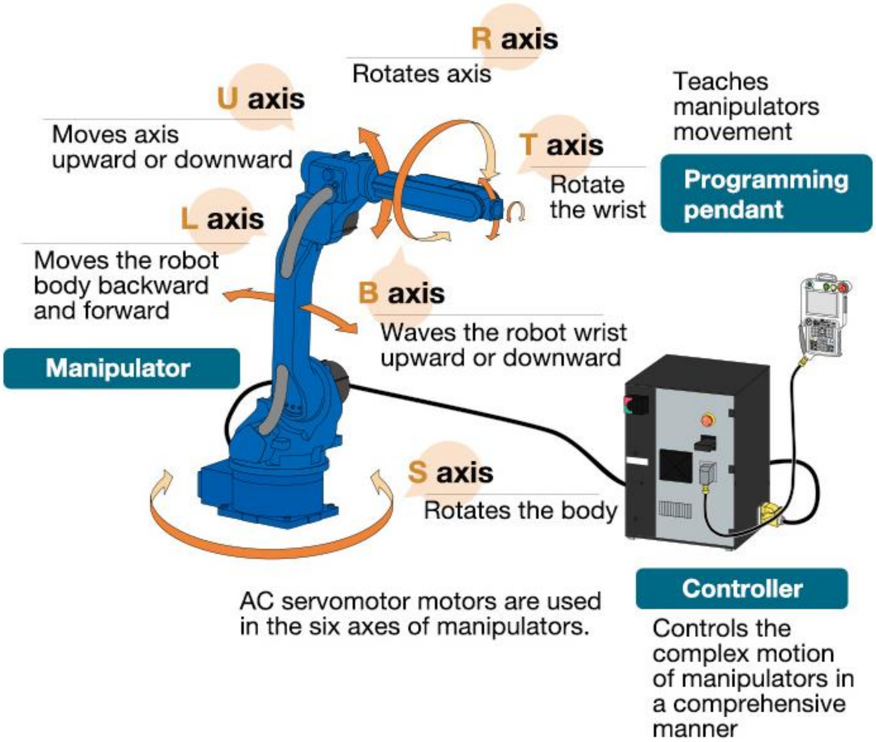

Fig. 5 Degrees of Freedom, Source: [31]

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C. Building Blocks of Industrial Robotic Arms

An industrial robotic arm is consisted by the following elements, which are integrated to form as a whole [29] [33]:

- Controller
- Teach Pendant
- Manipulator
- Actuators
- End Effector
- Sensors and Vision Systems

The controller is the brain of each robotic arm [31]. Its main function is to interpret the robot's application program and convert the commands in the source code to motion or other commands given to the drive's amplifiers. The robot controller has an internal model of the kinematic and dynamic structure of the robot and has advanced trajectory planning and synchronization capabilities. It can synchronize the motions commanded by each individual drive's amplifier in a precise manner. A robot controller also has thousands of parameters to make sure that the robot can be set up according to the requirements of its task.

Teach pendant is multifunctional portable equipment used to program and teach an industrial robot. The robot is moved manually and each point is recorded. The robot, then, moves from one point to the next automatically. The end of arm tooling (EOAT) or end effector is also programmed with the teach pendant. All teach pendants are equipped with an emergency button [33].

Manipulator is also called as robotic arm. It consists of links and joints. A manipulator does not include the end effector.

Actuators are the "muscles" of the robotic arms as they move their joints. Common types of actuators are servomotors, stepper motors, hydraulic and pneumatic cylinders and others. For example, each axis of a robotic arm is controlled by a servomotor [27].

End Effector is a device connected on the wrist of the manipulator. It handles objects and it can vary in size and complexity from simple pinch grippers to multi-finger grippers to welding tips, grinders, glue guns, screw drivers and others [33].

Sensors and vision systems are used to collect information about the internal state of the robot or to communicate with the outside environment [33]. They have the ability to scan the surrounding environment and stop in case of an obstacle or reduce the speed of the robotic arm in case of human approach. Some categories of sensors are optical, ultrasonic, vibration and wave sensors.

D. Modeling of Industrial Robotic Arms using BPMN 2.0

Every industrial robotic arm has a control panel, which is a collection of electrical components that are used to monitor and control the industrial robotic arm, the teach pendant, which is a control box, usually a touch screen for programming the movements of the robotic arm and the manipulator, which is an electronically controlled mechanism that performs tasks by interacting with its environment [29] [33]. As figure 6 shows, the block diagram of a robotic arm starts with the power supply that takes AC voltage from an external source and through the main circuit breaker distributes it to the internal components of the industrial control panel.

The main circuit breaker is where the power comes into the control panel for all the devices [34]. Moreover, it interrupts the power supply of the entire control panel if the e-stop button is pressed or the sensors detect a false parameter. Additionally, control panels are supplied with surge suppressors that provide protection against power surge. Continuing in the diagram, the AC supply from the main circuit breaker delivered to AC power distribution, which supplies the power supply, the power supply of the servo drive module and the Programmable Logic Controller (PLC). Power supply's function is to convert the AC to DC supply as the majority of the components inside a control panel operate on DC power, especially the fans of the control panel, the sensors of the manipulator and the teach pendant if it is wired.

It is worth noting that there are teach pendants that are wireless, battery operated and communicate with the controller via wifi connection. However, they have some drawbacks, such as loss of wifi connection, security of wifi connection and autonomy and thus, discouraging businesses from using wireless teach pendants.

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PLC is an industrial digital computer that can carry out pre-programmed outputs based on inputs and a set of specific rules. In other words, it continuously reads from sensors, like motor encoders, force sensors, or even vision sensors, and updates the actuator's commands, so as to achieve the desired robot behavior [33] [34]. At a rate of a thousand times per seconds, the PLC evaluates the environment and then, sends low-power signals to servo drive of each joint telling them what to do. Depending on how many axes a robotic arm has, it has equally many others servo drives and motors [29]. The servo drive, through the amplifiers, sends high-power current to the permanent-magnet synchronous motor (PMSM), which produces the forces and torques that drive the robotic arm through the actuators. PMSM has a gearbox that reduces or increases the speed with the torque output to be the inverse of the speed function. In addition, the robotic arm's motion and forces are measured by servo drive position sensors that send the measurements back to servo PLC through the servo drive control module. Finally the process is terminated with the motion of the various joints and links of the manipulator, which in turn move the end effector.

What is more, it is important to note that if the user of the teach pendant presses the emergency red button (e-stop) then, the circuit breaker is tripped resulting in power outage [34]. The same situation occurs when a sensor detects an error in its parameters, such as if the motion sensor detects proximity of a human. It should also be noted that the figure 6 depicts a centralized robotic arm with the control panel to contain most of the electronic modules that control the manipulator. Combining components mean fewer parts, fewer connections and greater convenience.

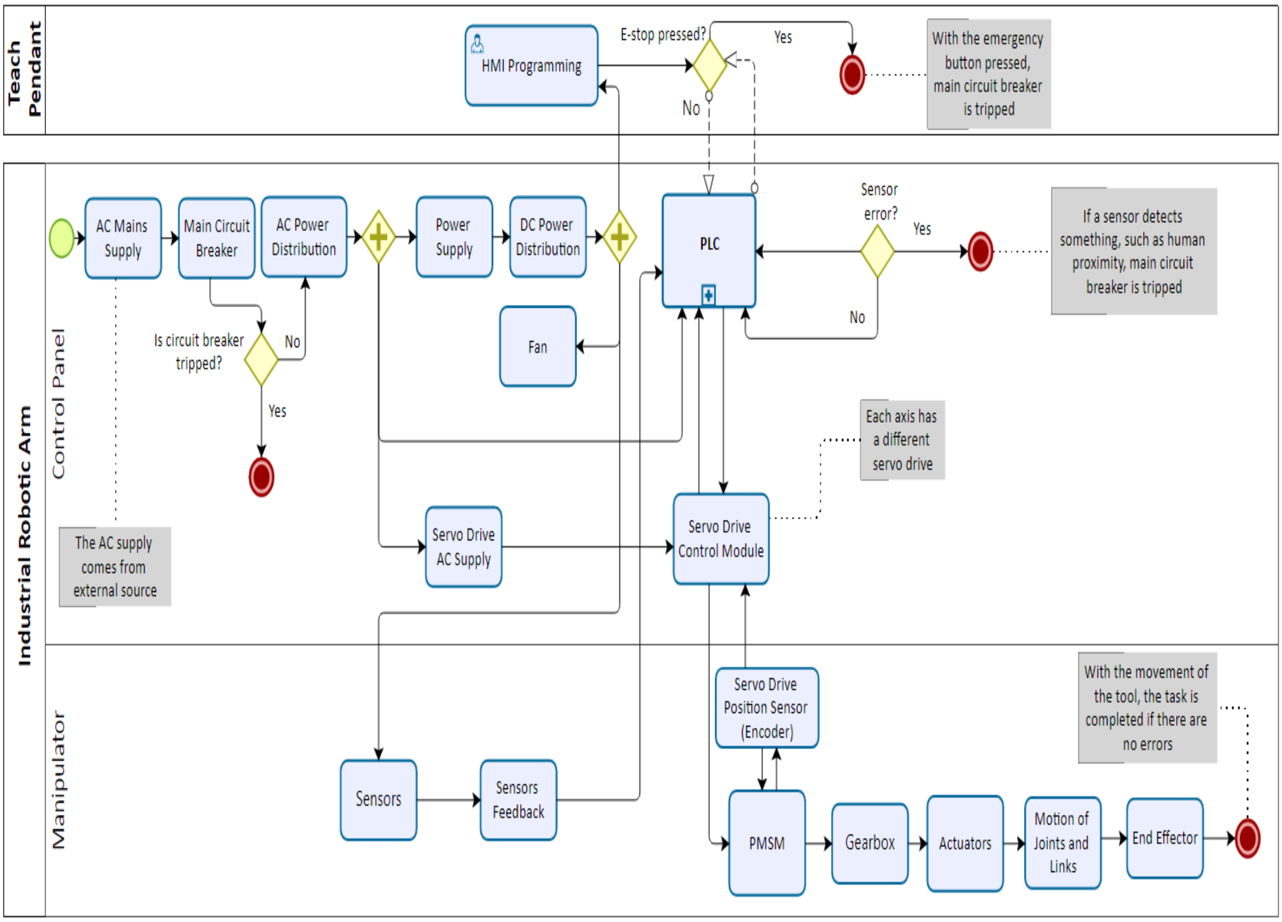

Fig. 6 BPMN 2.0 industrial robotic arm block diagram

In the above image, the PLC represents a sub-process that consists of several modules. The PLC also contains racks, which hold all the modules in areas that called slots [35] [36]. The most important modules are the power supply module, the Central Processing Unit (CPU), analog and digital input/output (I/O) modules and communication module. Initially, the AC supply coming from the AC power distribution of the control panel goes to power supply module, which provides the necessary DC supply to other modules of the PLC. CPU module owns the most significant part in a PLC, as it is the brain of the entire system. Its main function is to receive inputs, process the program that is written and energize the outputs based on that logic.

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The memory of the CPU module stores the programs and data from the teach pendant, as well as the signals from the other modules, and the microprocessor's processes that stored data in order to perform the required actions.

Moreover, a PLC has input and output modules [35] [36]. The input module refers to the devices that extract information from the physical environment and transfer it to PLC with the form of electrical signals. The input module is divided into analog and digital module. Analog input module contains inputs with a range of constant values like temperature, motors, pressure, etc. While digital input module accepts inputs with binary states like switches, push-buttons, photo-sensors, etc. Likewise, the output module is divided into analog and digital output module. An analog output can signal motors and valves for example, while a digital output can signal relays, solenoid valves and indicating lamps [36]. Lastly, the communication module contains network ports for communication of the CPU module with the teach pendant or other external devices. Teach pendant and PLC connect and communicate with each other using an industrial protocol such as, Profibus, Ethernet/IP and Modbus. The image below illustrates the interaction of every task, with the CPU module to be responsible for the final orders and decisions.

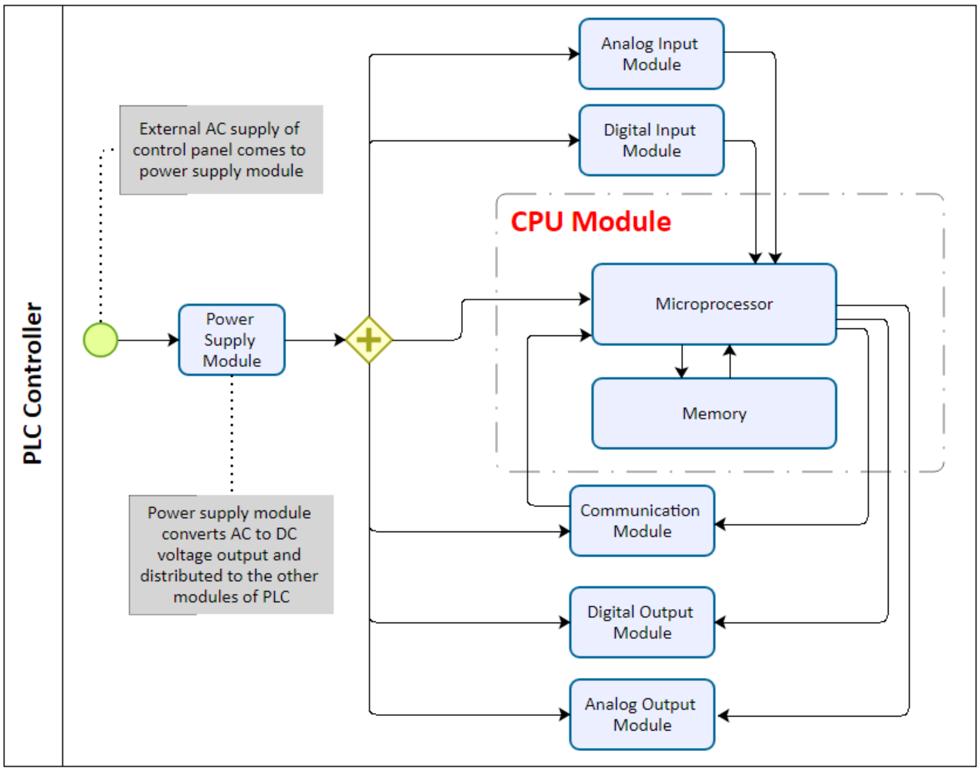

Fig. 7 PLC controller block diagram

Admittedly, the main factor in an industrial automation system and, more specific in industrial robotic arms, are servos. Servo is a device that produces motion in response to a command. Then, it regulates the speed and direction of this motion in response to feedback [29] [37]. They are widely used in robotic arms where precision, swift response to commands and exact fidelity to position requirements are necessary. There are many types of servo but industries use AC servo motors in recent years as they are more suitable for high repetition and precision. The AC servo systems involve two basic components, the servo drive or amplifier and the servo motor [38]. Initially, the servo driver receives AC power supply from control panel, which is rectified in DC through the converter. In order to control the output voltage supplied to the servo motor, the DC voltage fed to the inverter is varied by a voltage booster [37].

The DC voltage is set to a relatively low voltage for rotation of the servo motor in low revolutions per minutes (RPM) but, when the servo motor rotates at RPM, the DC voltage is boosted. At the same time, the servo amplifier takes in low voltage commands for torque, speed, position and amplifies them into a high-powered format that the servomotor can use [39]. Servomotors on the other hand, consist of powerful magnets, which accuracy and speed are achieved. In addition, the servomotor has a feedback device, which called encoder and which sends electrical signals back to the amplifier [29] [40]. The amplifier in turn uses the data to control the motor's position, speed and torque.

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The controller provides the commands that dictate when and how the servomotor will move. The commands from controller go to the amplifier in a form of an analog signal. The controller and the amplifier also exchange position feedback from the encoder [40]. The following image shows schematically the process that described.

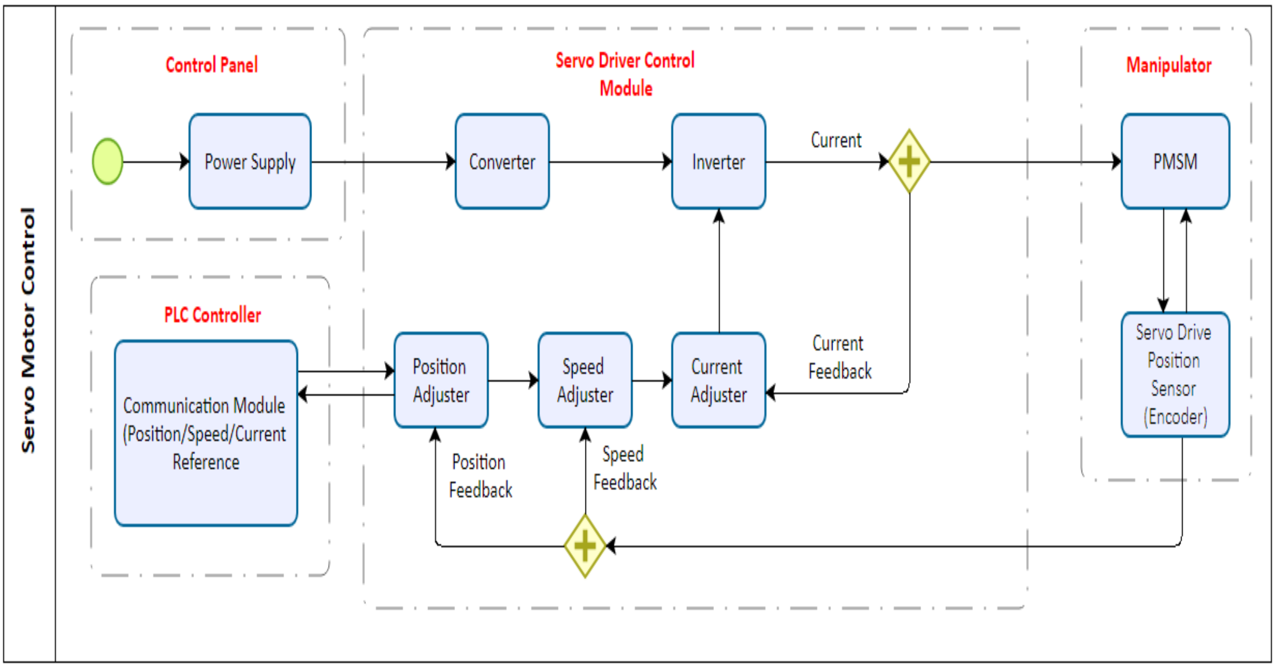

Fig. 8 Servo motor control block diagram

IV. CONCLUSION

In the present paper, we have relied on the theoretical background of BPM and modeling of business processes through BPMN 2.0, with main aim to present the internal procedure of the industrial robotic arms. The process diagrams that implemented form a good basis for BPM activities of an industrial robotic arm, in general, since through them, the representation, the observation and the analysis of the business processes are possible. Hence, based in this analysis existing processes can be changed where the applied changes can be simulated observed for any improvements. On top of that if a business is constantly modeling its processes, then, it will undergo permanent improvements with positive impacts on its efficiency and effectiveness.

It is also a fact that the more complex a process is, the more crucial its modeling is, in order to be understood by all involved, even by those who are not familiar with the internal functionality of the processes. This way, the stakeholders, technicians and executives, will be able to communicate better and to be at the same pace due to the simplicity of the modeling of business processes. BPMN 2.0 also enables in-depth analysis of a process in an intention to fully simplify it, as well as the role of each participant in this process. Last but not least, proper reorganization of problematic processes requires proper modeling; otherwise an existing process may worsen rather than improve.

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