Morita, R Journal of Engineering Research and Application *www.ijera.com*
ISSN : 2248-9622 Vol. 9,Issue 3 (Series -II) March 2019, pp 43-59

RESEARCH ARTICLE OPEN ACCESS

The Enabling Technologies of Industry 4.0 in the Development of New Products: A Case Study in Companies of the Automotive Segment

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ABSTRACT
Contextualization: Nowadays, with the emergence of the well-known Industry 4.0 or 4th Industrial Revolution, marked by the convergence of digital, physical and biological technologies, the enabling technologies have been strongly associated with the accelerated introduction of goods and services with high added value to the market and development of new products emerges as one of the fundamental pillars for organizations to remain with their long-term business activities. Enabling Technologies of Industry 4.0 such as Internet of Things (IoT), Computational Simulation, Virtual Simulation, Big Data, Cloud-Based Manufacturing, will enable products even after they enter the post-development phase. The post-development phase comprises from the product launch to its systematic withdrawal from the market and finally an evaluation of the entire product life cycle is carried out so that the experiences faced are counter-posed to what was previously planned, serving as reference to future developments. As a result, products continue to evolve throughout their entire life cycle. Products and manufacturing machines become more "intelligent" and connected to the World Wide Web, will dictate new models of business management, especially during the phase of product development.
Objective: This article aims to address the following aspects: a) analyze the management model of the existing product development process in the organization and explore the implications that the enabling technologies of Industry 4.0 (I 4.0) are exerting on the strategic decisions; b) analyze the implications of enabling technologies on the engineering and manufacturing of new products.
Methodology: In this article, in the first instance, was carried out an exploratory bibliometric study then analyzed the implications of enabling technologies on traditional models of management of the product development process through a case study of an auto parts industry. The study was qualitative-descriptive, characterizing the process of development of new products in the company surveyed. Interviews, semi-structured questionnaire, and documentary analysis were used to collect data.
Results: The expected result on the analyzed company was to identify the type of strategic model adopted, taking into account mainly the product development phase, that is, which factors the company takes into account during the product design and development process.
Implications: The study was limited in the search for articles from the period 2000 to 2018, and the survey was conducted in a medium-sized company located in the interior of the State of São Paulo from October to November 2018.
Originality: It is expected to demonstrate, through the research, the importance of the enabling technologies on the new management models of Research and Development (R&D) activities, that is, to analyze the influence that Industry 4.0 is exerting on the way in which strategic decisions are made in the organization.
Keywords: Industry 4.0; IoT; Big data; Virtual Simulation; product development.

Date of Submission: 21-02-2019 Date of acceptance: 10-03-2019

I. INTRODUCTION

The pursuit of competitiveness, once associated with continuous quality improvement, cost and price reduction, increased productivity, rapid and effective introduction of high value-added goods to the market, is increasingly dependent on the creation and renewal of associated competitive advantages learning, the quality of human resources and the productive capacity of enterprises (PRAHALAD e HAMEL, 1990).

This paper, through empirical evidence of the Brazilian economic situation, focused on the case study of a multinational company in the automotive segment. According to the Brazilian Ministry of Industry, Foreign Trade, and Services (2018), the automotive sector accounts for about 22% of the Gross Domestic Product (GDP) and

4.0% of GDP, with annual revenues of US$ 59.1 billion. According to Valor Econômico newspaper (2018), the new government's Rota 2030 program will require R $ 5 billion to be allocated to annual R&D investments.

Thus, some questions arise during the research: What factors to consider during the development process of innovative products? What are the main factors considered during the investment phase for R&D? What is the impact of using the I 4.0 enabling technologies on the product development phase? What are the advantages and disadvantages?

For the development of the study, an exploratory bibliographical and bibliometric review on the subject was carried out, as well as collected and analyzed data provided by the company - a case study; or from public domain material; and interview - survey, with the company's R&D division and applied a semi-structured questionnaire.

II. THEORETICAL FRAMEWORK

According to Cooper et al. (2001), the Product Development Process is subdivided into the following phases: Requirements, Definition, Design, Implementation, Production, Maintenance, and Product Withdrawal in the Market.

The Requirements phase comprises the conceptual development process of the product. It is composed of a multifunctional team with members of marketing, design, production and management. Marketing becomes responsible for specifying what potential customers need. The designers translate these requirements into concrete proposals. Production members define what can be developed, and management becomes responsible for ensuring that the concepts are in line with the company's decisions, objectives and strategies.

In the Definition phase, the requirements that are associated with the project result are specified as clearly as possible.

Once the team has agreed to the concept as a whole, the designers begin the work in more detail in the Design phase. The design is part of the concept drawings for more detailed drawings, a model and a prototype. It is important to note that during each stage, the design team should present the work to the entire team for periodic feedback.

The project takes shape during the Implementation phase. This phase involves building the actual project outcome. Programmers are busy with coding, designers are involved in the development of graphic material, and contractors are building the physical location of production. It is during this phase that the project becomes visible to outsiders, to whom it may seem that the project has just begun.

In the Production phase, the team completes the design and test steps correctly, the manufacturing step will result in the desired product with the projected cost. The team has to decide on the size of the production to ensure they can meet the anticipated demand and take advantage of economies of scale for larger executions.

The Maintenance phase concerns the monitoring of the product since its introduction in the market and can have a crucial impact on the longevity and profitability of the product. Effective product maintenance often has a significant life extension effect on the product. Continued product development can also contribute to strengthening competitiveness and longevity.

When adapting a product, considering the Product Withdrawal phase in the Market, the team should question whether future potential sales justify the cost of making changes. Eventually, a product requires such extensive changes to adapt it to new customer preferences that the costs become high and infeasible. The team should plan to close production and sales of the product and replace it with a new one.

In this way, enabling technologies from I 4.0, can be used as a means of continuous product evolution, even after entering the post-development phase. According to Mussomeli et al. (2018), computer simulation has been used for a long time with the main objective of improving the design of almost all physical products or processes, making it possible to evaluate a wide range of alternative designs before the physical prototyping phase. Simulation has also been used as a way to model different operating scenarios to develop control strategies that are incorporated in control algorithms to improve operations. The emergence of the Internet of Things (IoT) has created the potential for a transformation journey in which a product or process simulation model is linked by the Internet to sensors that capture data and actuators controlling its operation. The result of this is the so-called digital twin of the product or physical process that can be used to analyze and diagnose its operation and optimize its performance and maintenance in real time. Using the simulation in conjunction with the IoT, as Figures 1 and 2 illustrate, companies can analyze the performance of products under real operating conditions and make reliable predictions about future performance to improve product operation and productivity and reduce and the risk of unplanned downtime.

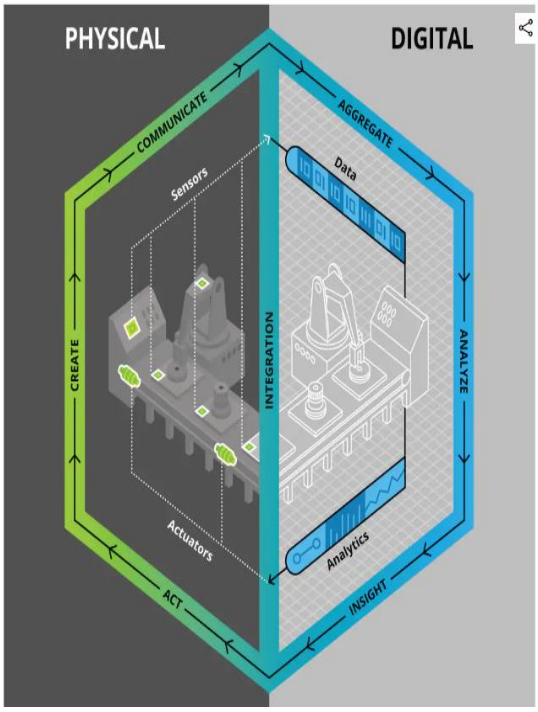

Figure 1. Manufacturing process model with digital twin.

Source: Deloitte University Press (2017).

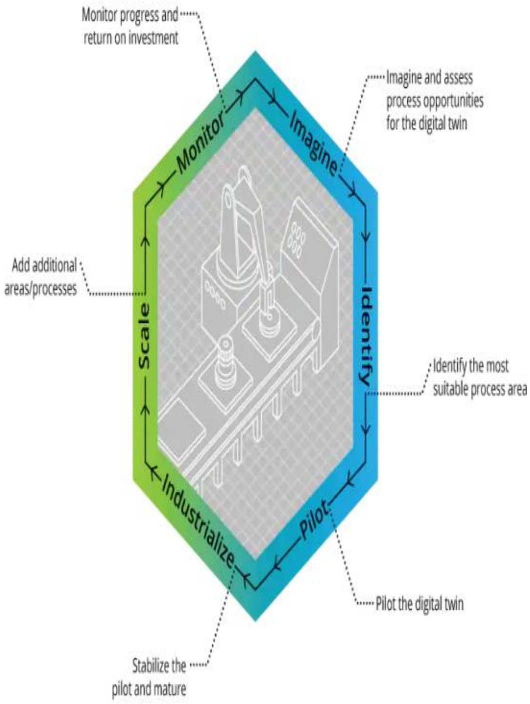

Figure 2. An overview of the application of digital twin.
Source: Deloitte University Press (2017).

Big Data can be adopted by companies throughout the value chain (research and development of new products, supply chain, production, marketing and sales - including after-sales). According to Casalinho (2015), the term Big Data currently refers to the large amount of data that is present in companies when associated, for example, to high speed processors, speed in obtaining data. Big Data therefore refers to datasets that are much larger in size than most typical database software has the ability to capture, store, manage, and analyze.

This certainly has some implications for organizational managers: a) it identifies the potential value of creation (weaknesses and opportunities); b) develops internal capabilities to create a "data-driven organization"; c) develop information strategies for the implementation of technologies; d) develop policies that align the interests of companies that want to create value through data and consumers who expect to protect their privacy and security (MANYIKA, 2012).

According to Kim (2009), Cloud Computing represents a convergence of two major trends in information technology: (a) IT efficiency, in which the power of modern computers is used more efficiently through hardware and software, and (b) business agility, where IT can be used as a competitive tool through rapid deployment, parallel batch processing, use of business-intensive computing, and mobile interactive applications that respond in time to user requirements. According to Avram (2014), cloud computing is not so much a technology as a combination of many pre-existing technologies. These technologies matured in different rhythms and in different contexts and were not conceived as a coherent whole; however, they came together to create a technical ecosystem for cloud computing. New advances in processors, virtualization technology, disk storage, broadband Internet connection, and fast, inexpensive servers have combined to make the cloud a more attractive solution.

According to Wu et al. (2014) Cloud-Based Manufacturing (CBM) is a decentralized and networked form of manufacturing based on many enabling technologies such as Cloud Computing, Social Media, Internet of Things (IoT), and Service Oriented Architecture (SOA), which structure this new manufacturing paradigm. Recently, with the emergence of Cloud Computing, marked by the introduction of a model capable of providing ubiquitous, convenient, on-demand network access to a shared network with a set of configurable computing resources (for example, networks, servers, storage , applications and services), provisioned and released quickly with minimal management effort or interaction with the service provider (MELL and GRANCE, 2011), CBM becomes a promising manufacturing paradigm that drives new manufacturing business models. For example, CBM allows service consumers to easily locate qualified service providers, manufacturing services such as CNC machining, injection molding, or 3D printing through a crowdsourcing process (distribution of problem solving and online production model).

Digital manufacturing uses additive manufacturing systems, also known as rapid prototyping or restrictive manufacturing, also known as CNC machining. Additive manufacturing systems are based on the addition of layers to obtain the product. In restrictive manufacturing, the final product is obtained by the progressive removal of material. Both in additive manufacturing and in restrictive manufacturing, the first step is the creation of a virtual model, developed in computer aided design (CAD) software, that allows the generation and manipulation of complex geometric shapes in three dimensions. In these softwares it is possible to assign different types of materials, textures, volumes and shapes to the pieces to study aspects such as fitting between parts and assembly and disassembly of the product. "The term rapid prototyping refers to usually to the production methods of prototypes by additive systems "(PIPES, 2010). With this method, it becomes possible to transform digital models with complex geometries into physical artifacts. The process of rapid prototyping is an "additive" process, since it combines layers of polymeric material to create a solid object, allowing the creation of objects with complicated internal characteristics that cannot be obtained through other processes (GORNI, 2001).

In addition, according to Patterson (1990), Artificial Intelligence can be described as a system that has the ability to learn new concepts and tasks, to reason and obtain useful conclusions about the world around us, to understand and understand body language. Thus, according to Rao et al. (1999), Artificial Intelligence and intelligent systems, can be used during the development activities of new products. Given the complexity of the product development process and the key role that product development plays in determining downstream production activities, artificial intelligence and expert systems can play an important role in manufacturing, reducing product development time, improving quality and reducing costs. The main application areas during the product development phase have been in product and process design, project evaluation, conceptual design (initial stage of product development), quality function and group decision making, as in simultaneous engineering - that is, "a systematic approach to the simultaneous and integrated design of related products and processes, including manufacturing and support. Such an approach seeks to involve stakeholders from the very outset of development on all elements of the product lifecycle, from concept to disposal, including quality, cost, deadlines and customer requirements. "(Winner et al. al., 1988).

1. The Case Study

1.1. The company

The company analyzed is a multinational supplier of automotive lighting and signaling systems. The company has a global presence with 22 factories in several continents (America, Europe, Asia, Oceania). It also has research and development centers in countries such as Japan and China.

It has as clients the automotive vehicle assemblers, which incorporate lighting and signaling products in their vehicles. The company analyzed, within the supply chain, can be classified as a tier 1 supplier. It means that the company supplies its products directly to the car assemblers. Vehicle manufacturers, in this context, can be classified as OEM (Original Equipment Manufacturers). Commonly, the other levels of the supply chain are classified by tier *x* (*x* represents the level in the supply chain in which they are).

The typical safety and lighting products produced by the company are represented by headlights and lanterns of automotive vehicles for passenger cars and pickup trucks for example. In figure 3, one can illustrate typical products, currently produced by the auto parts industry.

Figure 3. Typical safety and lightning products. Left: automotive headlamp with Daytime Running

Function (DRL) and dipped headlight; Right: automotive taillight with position function.
Source: AutoEsporte magazine (2017).

1.2.The current scenario of product development management

In the last decades, we have experienced a great increase of the speed in which new products have been introduced to the market. One of the main reasons is the development of new technologies, followed by the incessant need to reduce the costs of development and production, and the increase of the quality standards of the developed product. Because of this, it became necessary to analyze and develop new strategies and methodologies that can bridge the gaps left by the traditional product development approach. According to Rozenfeld et al. (2006), this approach was usually based on a sequential model in which the activities followed a logical and almost uninterrupted order between the functional areas of the company. At the end of the eighties, new management philosophy of the Product Development Process (PDP) emerges, with the main objective of coordinating the process more efficiently and efficiently. In this way, the simultaneous engineering approaches proposed by Carter and Baker (1992), stage gates proposed by Cooper (1993, 1990) and the unified model of Rozenfeld et al. (2006). This latter approach integrates previous models and reinforces the strategic role of product development, the need for functional integration, and the simultaneity of activities and information.

The specificity of the products that are integrated into the vehicles severely conditions the way the product development process (PDP) is performed, as well as the value chain. Some specifics applicable to the analyzed company can be demonstrated below:

- Concept, technical and functional specifications: OEM;
- Research & Development: tier 1, with typical duration of 2 ~ 3 years;
- Production: tier 1;
- Supply chain: strongly integrated;
- Quality: high requirements, quality management performed on the basis of industry-specific standards (IATF 16949, VDA, AIAG);
- Business processes: introduction of products on the market, technical assistance OEM.

III. METHODOLOGY

In order to identify the relationship between technologies from Industry 4.0 and the stages of the Product Development Process (PDP) proposed by Cooper (1993), an exploratory bibliometric study was initially developed, in which the main enabling technologies related to the segment automotive. Articles from the period 2000 to 2018 were selected with the Internet of Things (IoT) themes, Computational Simulation, Virtual Simulation, Big Data, Cloud Computing, Additive / Hybrid Manufacturing, Advanced Robotics, Artificial Intelligence, relating them to the Product Development Process. Through a treatment and data analysis, 20 articles were selected for the theoretical reference of bibliometric research, according to Annex A. From this, a semi-structured questionnaire was developed and applied in interviews with managers of the company. Research and Development (R&D) area, from October to November 2018, with the main objective of identifying the degree of importance that the enabling technologies of I 4.0 could imply on the strategic and decision-making of the analyzed company before the aspect of the Product Development Process. In addition, documentary analysis was carried out with the objective of identifying opportunities for improvement with the application of IoT, Big Data, Cloud Computing, Additive / Hybrid Manufacturing, Virtual Simulation, Advanced Robotics, Artificial Intelligence, before the processes the company.

IV. SEARCH RESULTS

In the case study presented, the company's PDP can be classified as the unified model proposed by Rozenfeld et al. (2006). The model is based on a series of stages of development and activities to be performed at each stage, as Figure 4 illustrates. At the end of each stage there is the so-called gate review (control gate) that is responsible for process quality control. The PDP of the analyzed company is basically composed by a set of four macro phases, with in each one of them one or more gates. Thus, the gate review indicates to the high management of the company any deviations from the process and the need for a greater monitoring of the project or allocation of additional resources.

In each macro phase, the team is managed by a manager responsible for coordinating all the activities inherent to the PDP as well as the relationship and communication with the client. The functional areas that integrate the same are commonly sales, engineering, manufacturing, logistics, supplies, finance and quality. Here are briefly summarized each of the macro phases:

- Customer Quotation - In this macro phase, the strategic planning of products (through the development of design concepts) is carried out and the company's commercial activity in the search for new business is developed.

Commercial proposals are also presented to customers.

- New Model - After the acquisition of a new project, one enters the macro phase of development and industrialization of the product. A team dedicated exclusively to the project is designated, especially in engineering, advanced manufacturing (responsible for the industrialization and product launch) and supplies. In this macro phase the technical and functional specifications of the product are defined, which will remain unchanged in the subsequent phases. It starts with project planning and ends 3 months after product launch;
- Current model - The product goes into production, on dedicated production lines that run up to 24 hours a day, according to customer's production demand. The project team is composed of elements from the manufacturing, quality and logistics areas. Since product changes are not planned, there are no dedicated engineering elements that are unique to the product. There is, yes, an engineering group responsible for several projects, which analyzes and corrects quality problems found in the product and implements cost reduction actions;
- Past model - The product is discontinued from the market, although there is a residual production for spare parts, with a period provided by law equivalent to twice the guarantee of the model year of the vehicle (Chamber of Deputies, 2017). Another design team is designated and dedicated exclusively to discontinued products on the market.

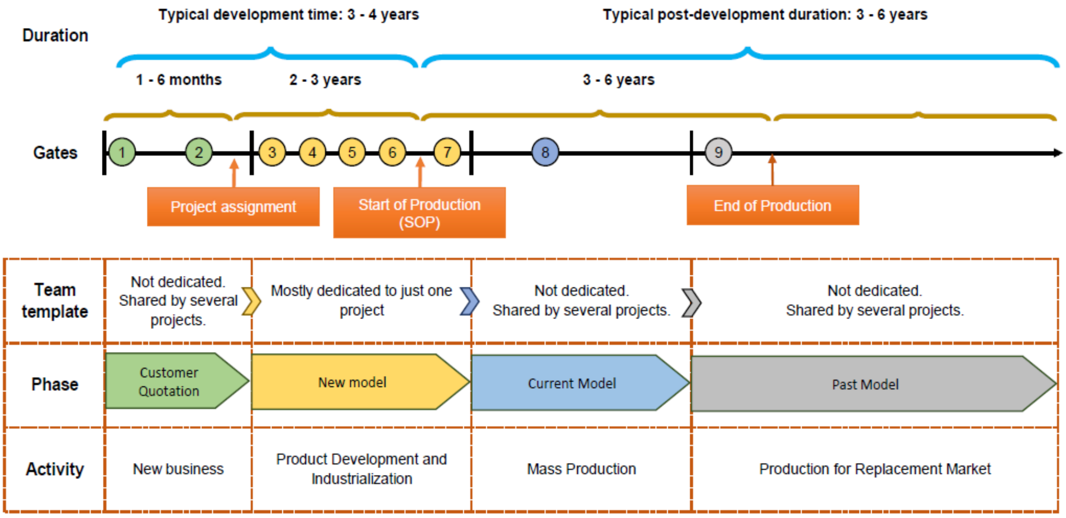

Figure 4. Macro view of the product development process.

During the client quotation process and definition of the future model, we identified through interviews with the managers and the semi-structured questionnaire analysis that there is a need to implement digital technologies such as IoT, Computational Simulation, Virtual Simulation, Big Data, Cloud computing. We interviewed 30 employees from different departments, such as New Product Development, Quality, Production, Process Engineering, Sales, Purchasing, Maintenance, Tooling / Molding, Injection, Metallization. Figures 5 to 24, illustrate the results obtained for the analyzed company.

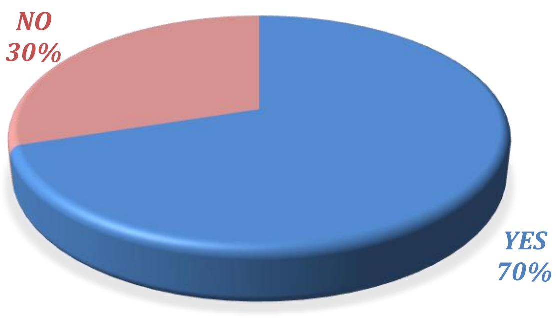

Figure 5: Application of IoT in the production lines, would it be advantageous for the company?

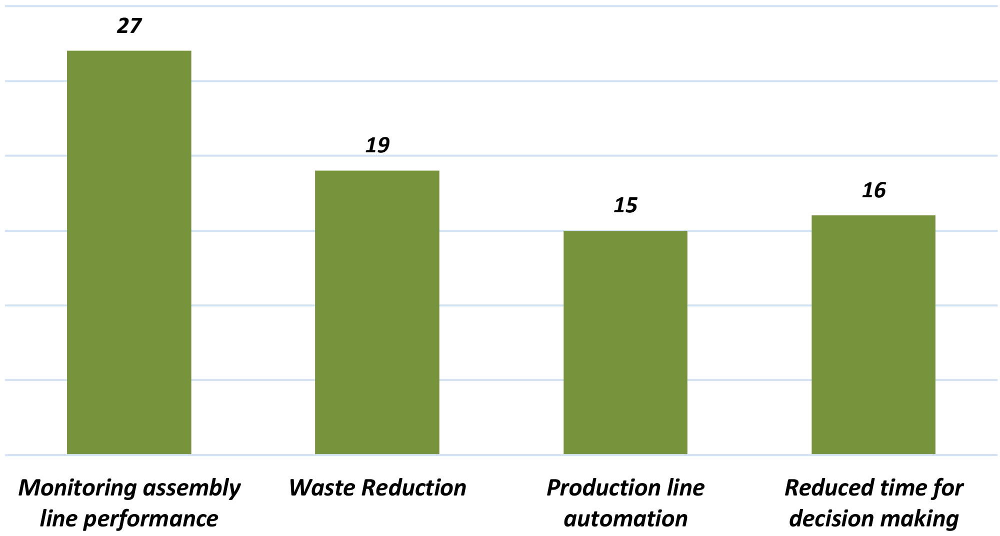

Figure 6: What are the main advantages of applying IoT?

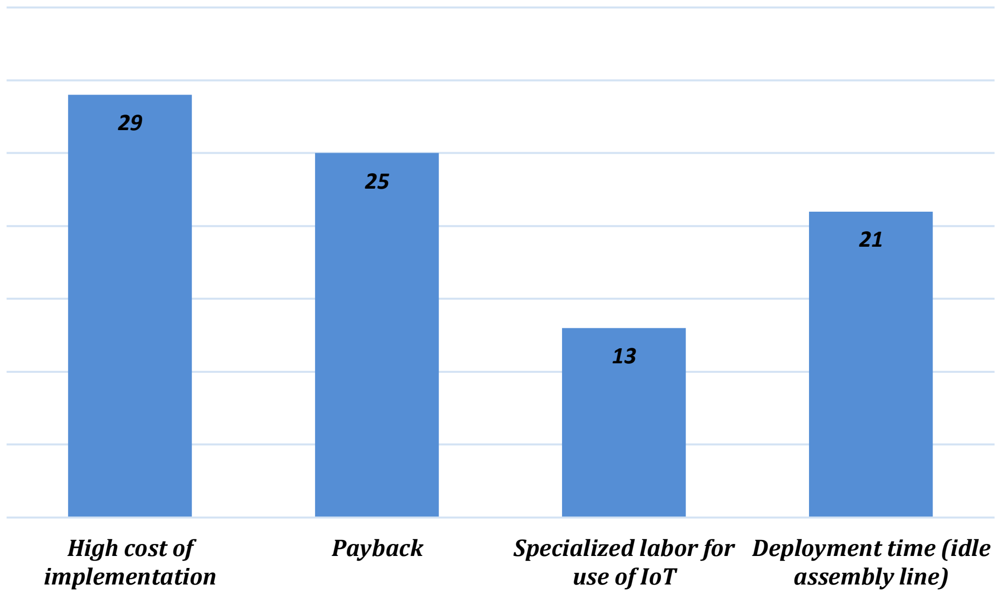

Figure 7: What are the main problems for the application of IoT?

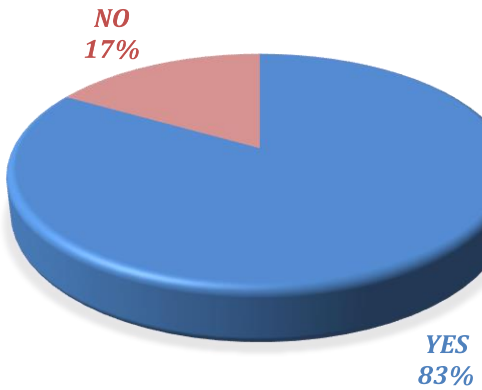

Figure 8: Would the virtual simulation application for the development phase be advantageous for the company?

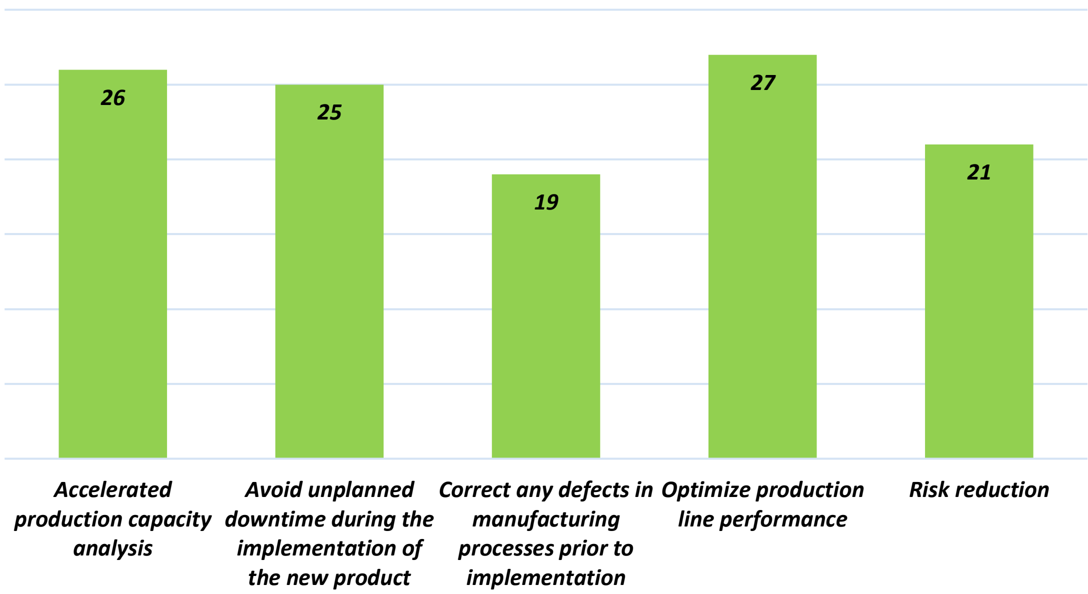

Figure 9: What are the main advantages of applying virtual simulation during the development phase of new products?

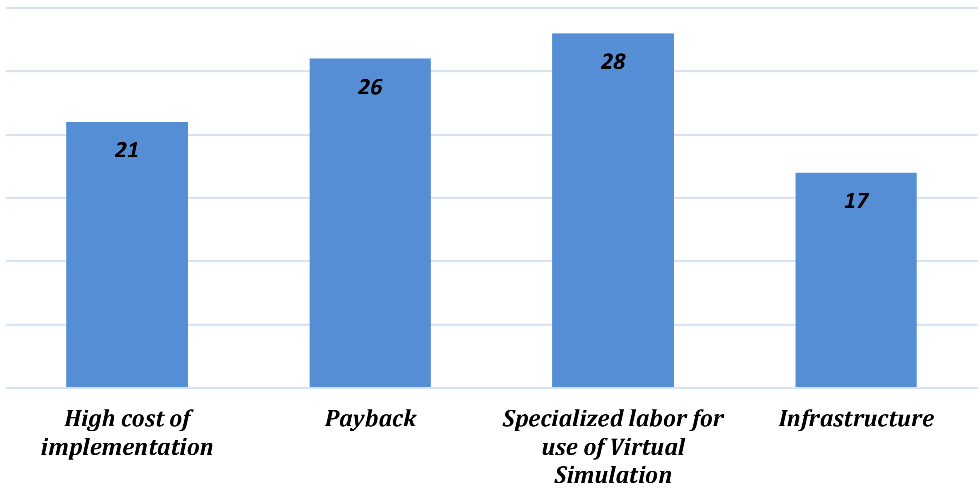

Figure 10: What are the main problems for implementing virtual simulation?

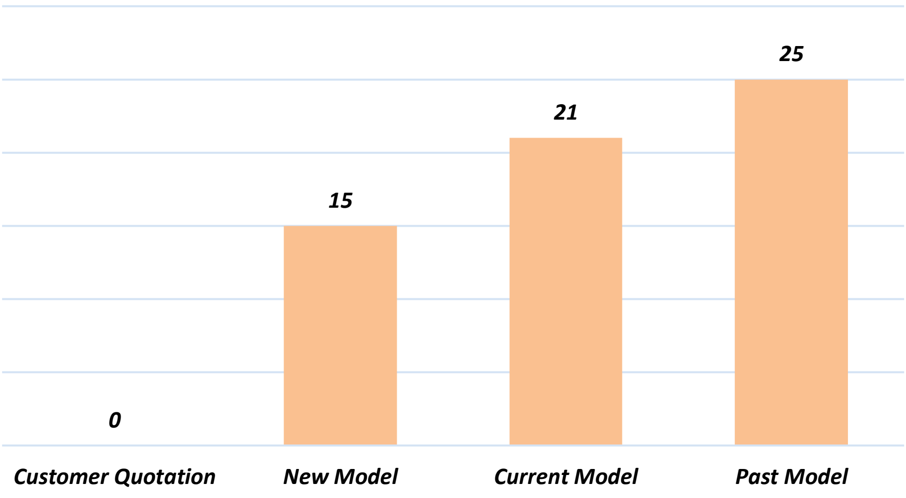

Figure 11: What would be the ideal stage for the use of IoT?

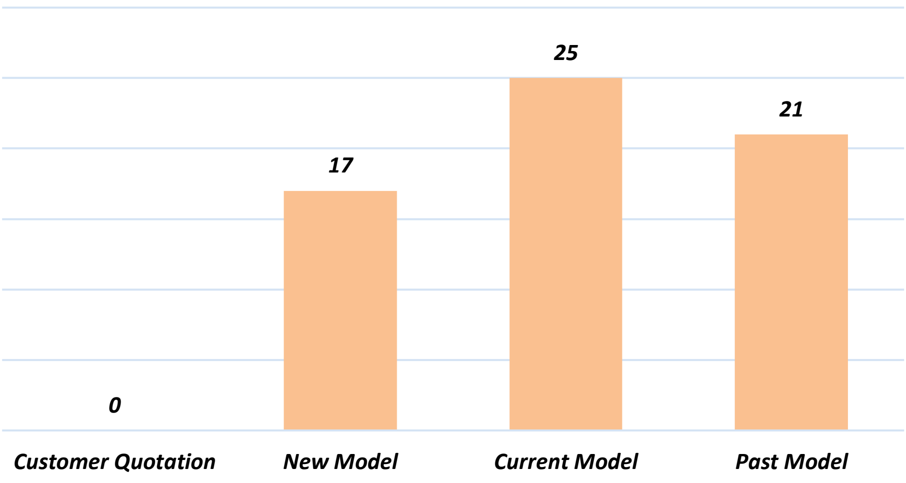

Figure 12: What would be the ideal phase for using Big Data?

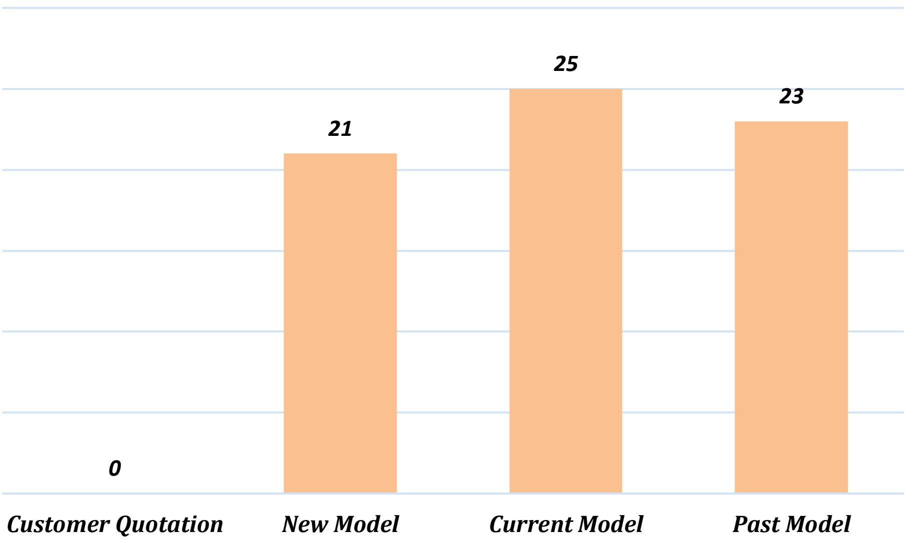

Figure 13: What would be the ideal phase for using Cloud Computing?

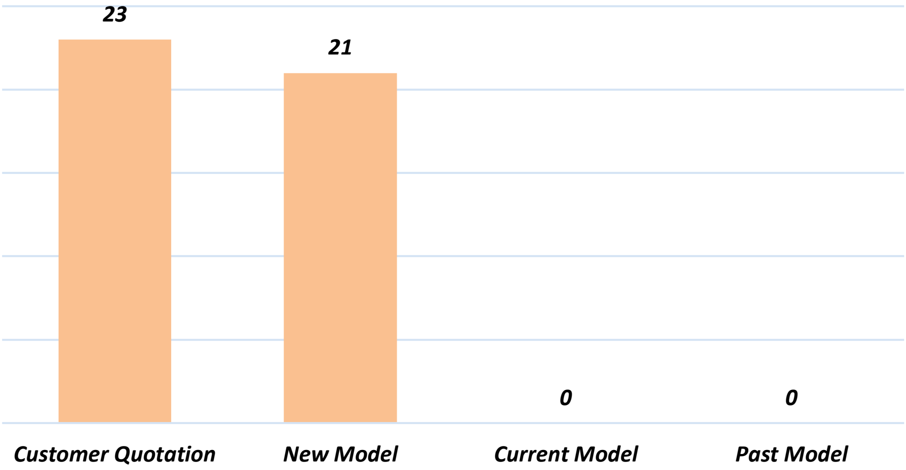

Figure 14: What would be the ideal phase to use Additive Manufacturing?

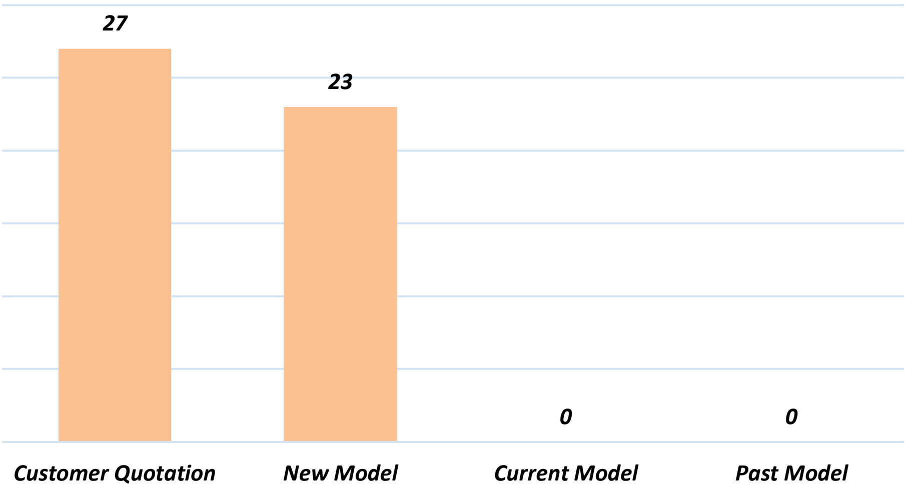

Figure 15: What would be the ideal phase for using Virtual Simulation?

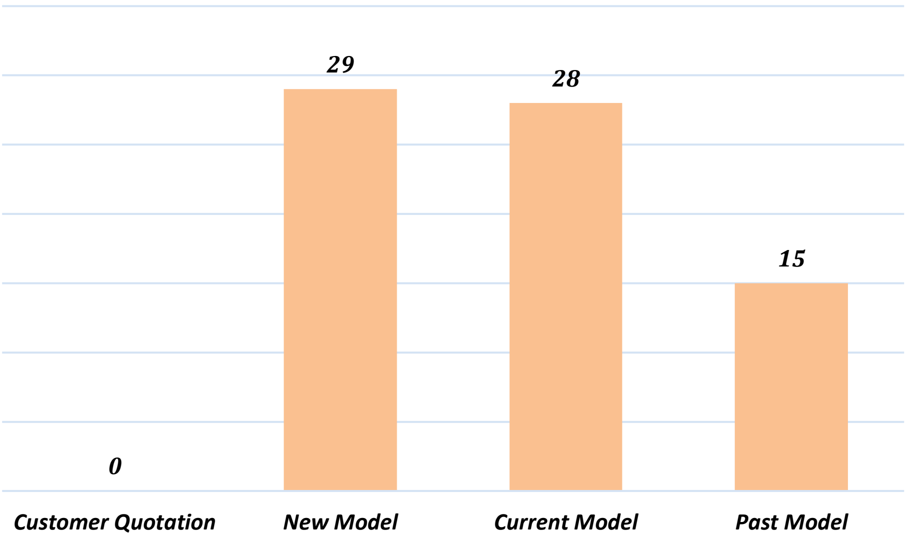

Figure 16: What would be the ideal phase for using Advanced Robotics?

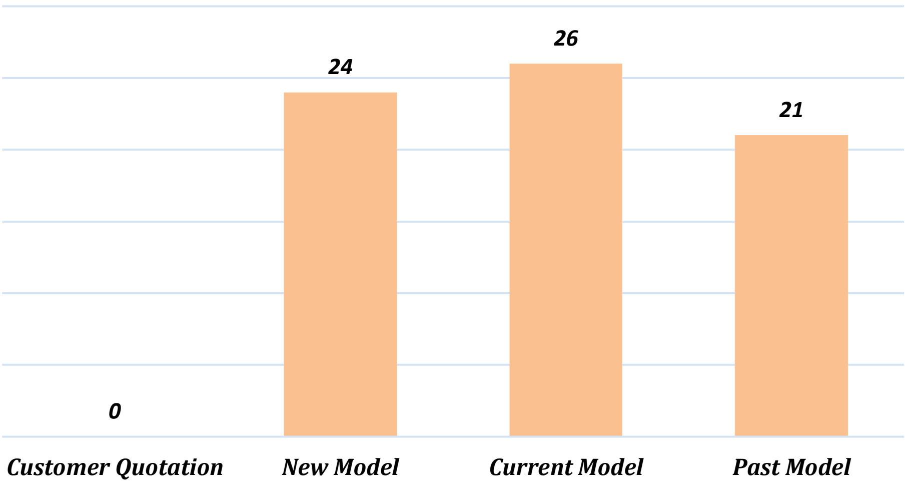

Figure 17: What would be the ideal phase for using Artificial Intelligence?

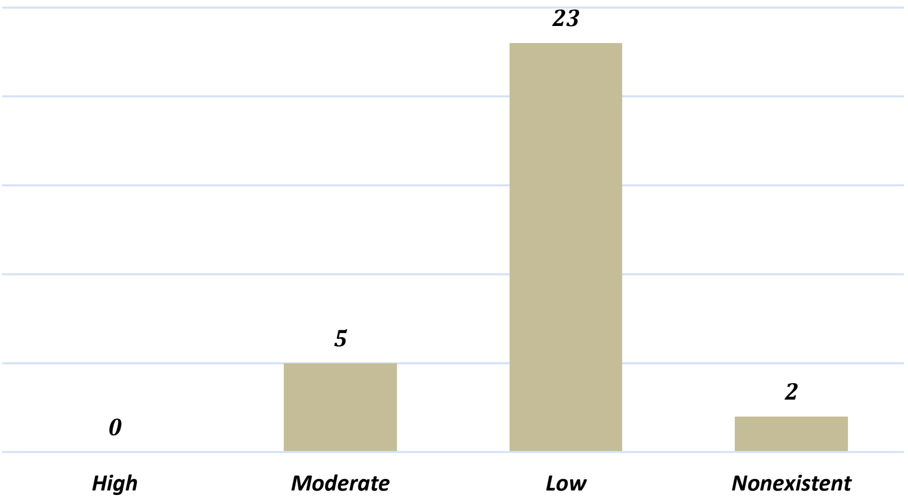

Figure 18: What is the degree of use of IoT in the company?

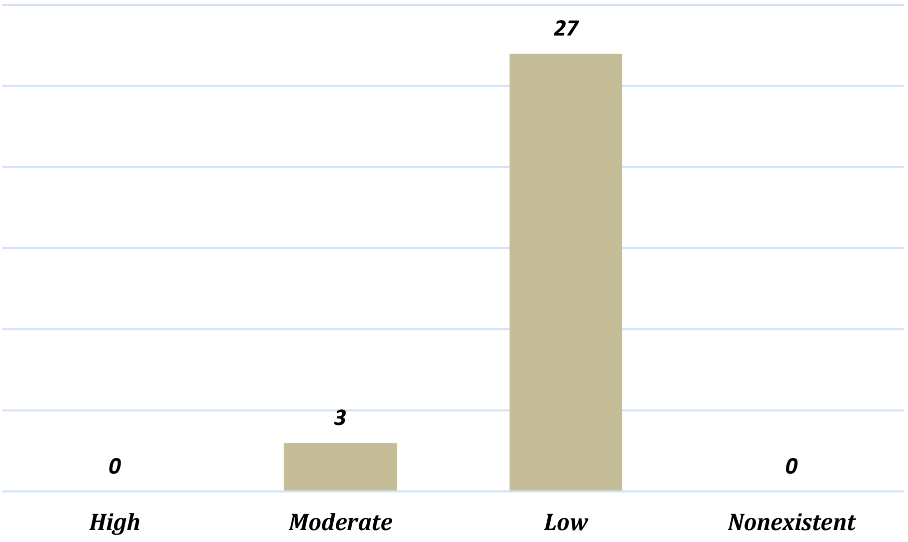

Figure 19: How Big Data is used in the company?

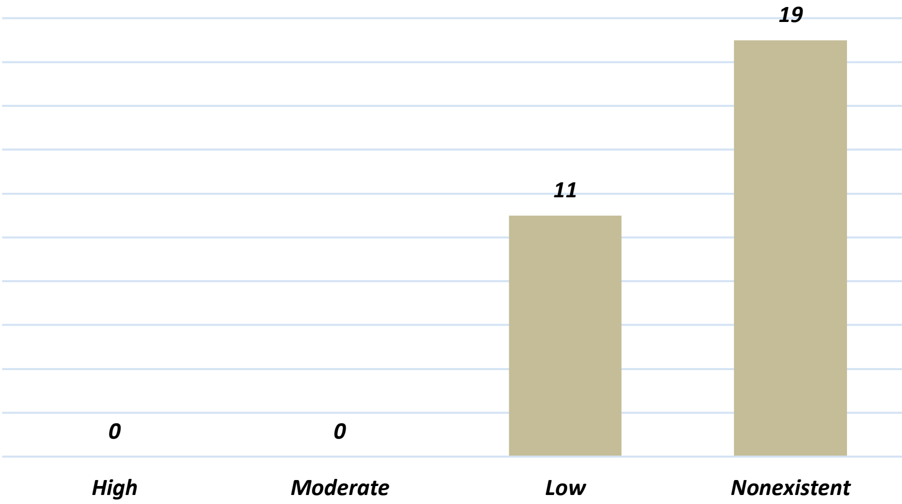

Figure 20: What is the degree of use of Cloud Computing in the company?

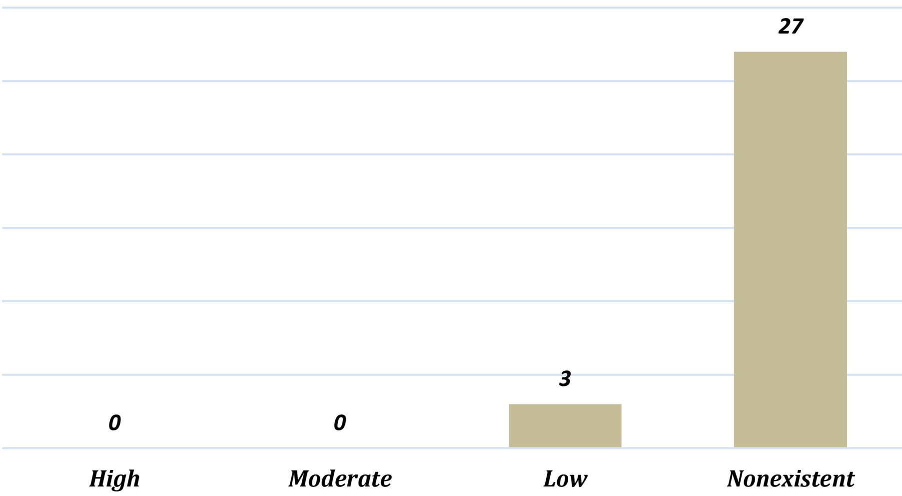

Figure 21: What is the degree of use of Additive Manufacturing in the company?

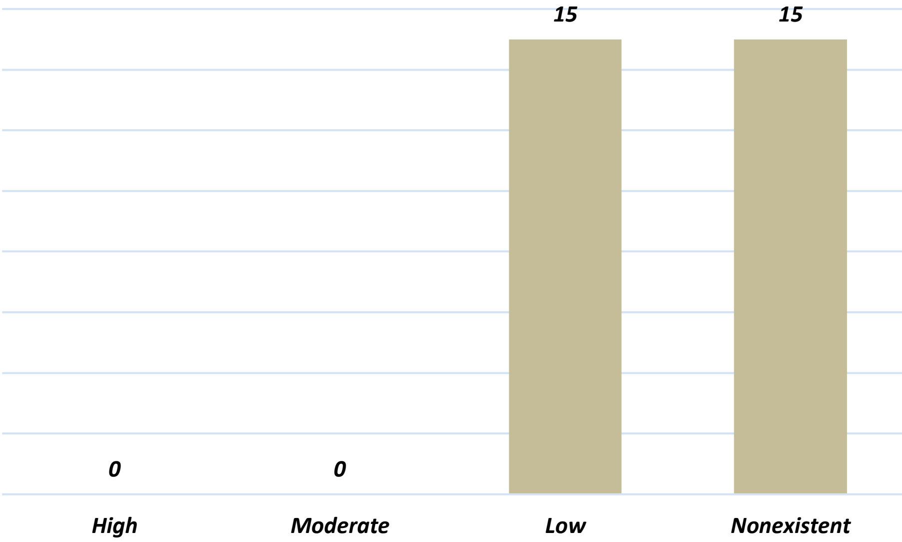

Figure 22: What is the degree of use of Virtual Simulation in the company?

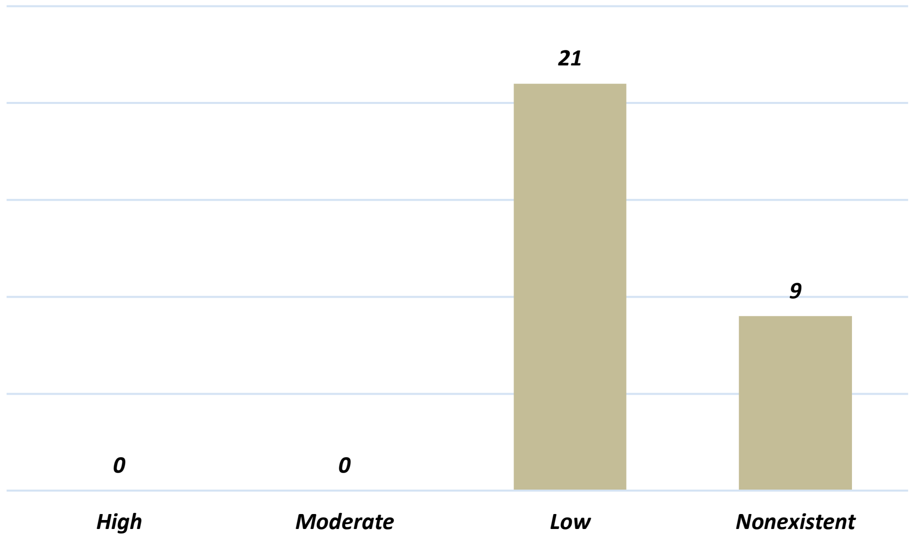

Figure 23: What is the degree of use of Advanced Robotics in the company?

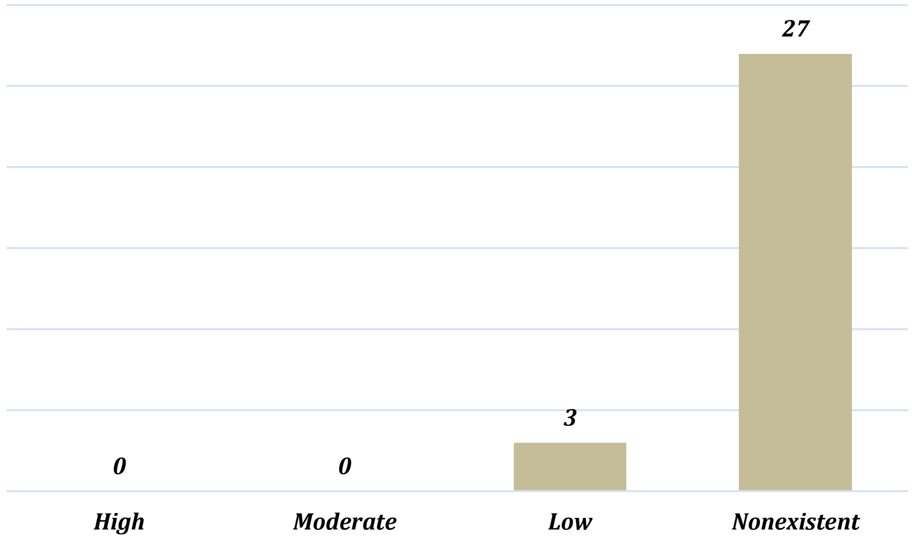

Figure 24: What is the degree of use of Artificial Intelligence in the company?

In this way, it can be noted that there are obstacles to be overcome in order for the Enabling Technologies of Industry 4.0 to be implemented. Issues such as high cost of implementation (all resources required for implementation), payback, skilled labor, or even specific training to enable assembly line operators (for resource use efficiently), implementation time the downtime of the assembly line), are currently the main obstacles to be overcome for successful implementation.

V. FINAL CONSIDERATIONS

The Internet of Things will bring about a profound change in the way companies are managed, especially during strategic decision-making. From this, the main objective of the study is to identify strategic points in which IoT can be implemented in order to increase productivity and reduce costs, as well as to maintain or even improve the quality of the product or process. An immediate example that can be analyzed for the use of IoT is the use of a network of sensors that can monitor the behavior of the production line, and by means of a cloud network (Cloud Computing), store the collected data (Big Data), drawing a behavioral production profile according to the model produced and simultaneously transmitting the information to the process managers, thus identifying "trends" in control charts (Process Statistical Control- PSC). In this way it will be possible to "anticipate" any problems that may arise during the manufacturing process of the product.

The digital simulation-based twin will help companies analyze machines and equipment under real operating conditions and make decisions that will improve their performance far beyond what is possible today. System-based simulations with big data analysis and industrial devices with embedded "intelligence" can reduce risk, avoid unplanned downtime, and accelerate new product development. The resulting efficiency and productivity gains will have a dramatic effect on the bottom line of an organization as well as the global economy. The combination of the machine's connectivity with a data management platform powered by engineering simulation will allow, for example, to perform diagnostics and problem solving in companies, determine the ideal maintenance program based on the characteristics of each machine or equipment, optimizing the performance of your assets, generating interesting data that can be used to improve the next generation of the product.

ANNEX A. Selected articles.

Keywords	***References***
Additive Manufacturing, Product Development	LINDEMANN, C.; JAHNKE, U.; MOI, M.; KOCH, R. Analyzing Product Lifecycle Costs for a Better Understanding of Cost Drivers in Additive Manufacturing. p. 177-188. 2012.
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