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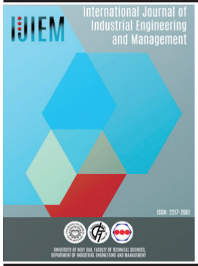

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The Technology Analysis model - TAM 4.0 for implementation of Industry 4.0

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ABSTRACT

The new production paradigm, Industry 4.0, seeks to improve the productivity of industries. However, to implement Industry 4.0, there is a need for high investments in modern processes/equipment, which can impact this implementation. The contribution of this paper is to present the Technology Analysis model – TAM 4.0, to support the management of manufacturing processes in deciding when to acquire new equipment/ processes or when to modernize existing ones (retrofit) to implement Industry 4.0. The model was evaluated and improved by experts using the *Delphi* method, being a theoretical contribution to the Industry 4.0 body of knowledge and also to practice, helping those involved in implementation projects.

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1. Introduction

Industrial revolutions are production paradigms that allow for significant changes in the industrial production processes [1]. The 4th Industrial Revolution, or Industry 4.0, brought great opportunities to the industries [2], [3], with a greater focus on the application of digitalization, integration of cyber-physical systems, robotization, artificial intelligence, and the storage and analysis of mass data, among others [4]-[7].

The modernization of equipment and production processes through the implementation of Industry 4.0 presents itself as an opportunity for the company in the quest to increase competitiveness and open possibilities for business development [5], but involves high investments in modern processes/equipment, which can impact this implementation, the aim of this study.

The implementation of Industry 4.0 brings challenges to the industries [8], involving technological and organizational aspects [9]-[11].

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At the organizational level, cultural changes are needed, as well as the development of previously unnecessary skills and the understanding that some previously essential skills may become obsolete [9]. As a challenge, the expected speed for changes to occur is added. The risks of industries arise mainly in the market, as there is a constant risk of the emergence of new competitors with innovative business models, what can make the processes of companies that did not modernize quickly obsolete [12].

At the technological level, the modernization of production processes in order to implement Industry 4.0 requires relatively high investments in technology. Investments in cyber-physical systems (CPS), infrastructure, information security, integration between systems, and digitalization, among others, add major challenges to companies that seek modernization towards the implementation of Industry 4.0 [8].

To implement Industry 4.0 technologies and concepts there is a need of investing in modern processes/equipment, or alternatively modernize existing ones (retrofit), which can be crucial for its implementation. However, there is a scarcity of models that support the management of manufacturing processes in this decision.

The models introduced in the literature present projects for new processes to support Industry 4.0 implementation, or projects related to solve technological problems with the installation of processes/equipment. Kolla et al. [13] present a proposal for the implementation of CPS in a machine tool, installing sensors in the physical layer of the equipment and installing network interfaces in the data digitalization layer of the equipment, thus enabling the acquisition and analysis of data from the equipment. Lins et al. [14] present a study in which they implement a CPS with the objective of modernizing a robotic arm prototype with Industry 4.0 concepts.

In a rare study on decision support to evaluate digital technologies under the Industry 4.0 approach, Medić et al. [15], present the FMADM hybrid model, where Industry 4.0 technologies were kept general to keep the model useful over time. However, future studies with technologies that enable Industry 4.0 are encouraged [15, p.10], but no other studies have been found in the scientific literature in this line so far, which is a gap in the research that this study intends to fill.

Given the need of deciding to invest in modern processes/equipment, or alternatively modernize existing ones, in the implementation of Industry 4.0, the following research question arises:

RQ1. How should a technology investment analysis model for the implementation of Industry 4.0 be, to assist in decision-making on the purchase of new equipment or carrying out a retrofit?

This study presents the Technology Analysis model - TAM 4.0 for Industry 4.0, to support the management of manufacturing processes in the decision on when to acquire new equipment and processes or when to modernize existing ones with Industry technologies. 4.0, based on the literature review, which was refined by experts using the *Delphi* method.

After this introduction, section 2 presents the theoretical background and section 3 explains the method used. Section 4 presents the results and discusses the model, and section 5 brings the conclusion, limitations and suggestions for future research.

2. Theoretical Background

The term Industry 4.0, the new productive paradigm, was coined at the Hanover fair in 2011, in Germany, as part of a high technology program by the German government to improve the technological level of German industries, when through the integration of the physical world to the virtual one, digitalization can be introduced in the industrial area, to improve productivity [16]-[20].

2.1 Industry 4.0 technologies

Industry 4.0 is supported by technologies that emerged before and alongside this industrial revolution, however existing technologies are constantly evolving just as new technologies emerge frequently, thus, new classifications for existing technologies, new technologies and adjacent technologies are always evolving and supporting the implementation of Industry 4.0 [21].

The isolated use of technologies does not necessarily classify a company or processes as an Industry 4.0, requiring a more comprehensive approach to integration between technologies and processes.

Here follows some relevant Industry 4.0 technologies: (1) *Cyber-physical system (CPS)* – promotes the integration and interconnection between networked cyber components and physical components; (2) *Internet of Things (IoT)* – Enables connectivity between people and objects, such as machines, mobile devices, actuators and others, making information and data widely accessible; (3) *Big data analytics* - Employed to handle and analyze large amounts of data; (4) *Cloud computing* – used to store and process data on servers not known where they are located, so said to be in the clouds; (5) *Automation with Cobots* – Collaborative Robots (Cobots) are robots that work in direct contact with humans, to assist in their daily activities, reducing risks and human efforts; (6) *Additive manufacturing* – By depositing material layer upon layer, a product is manufactured; also known as 3D printing, there are different technologies that can use different materials; (7) *Modeling and simulation* – software replicates processes/equipment to optimize layout and productivity, prior to actual operation; (8) *Cybersecurity* – It is essential that systems can be protected from cyberattacks, as the Internet is the way Industry 4.0 uses to communicate; (9) *Blockchain* - Using an encrypted database, this technology allows information to be shared in a form that cannot be tampered with; (10) *Drone* – It is an aerial vehicle that does not need a crew or pilot to operate it, being possible to operate it from a distance; (11) *Guided and autonomous vehicles* – They are used to transport goods and materials, improving material handling and logistical operations; (12) *Machine learning* - technology that seeks to provide the computer with the possibility of finding hidden insights without specific programming for such; (13) *Internet of Service (IoS)* - Through the Internet, IoS seeks to improve the interaction between all the various interested parties, made up of users, consumers, sellers and others; (14) *Semantic Technologies* - are characterized as languages that make it possible to go beyond syntactic representations, computationally describing semantic aspects of documents, supporting the use of ontologies; (15) *Virtual reality (VR)* – VR allows the user to feel present in a virtual environment in a immersive experience; (16) *Augmented reality (AR)* – AR expands the physical environment by including virtual objects in the real environment; (17) *Artificial intelligence (AI)* – System that makes it possible to interpret data and learn from it, adapting flexibly to perform tasks and achieve goals [11], [19], [22], [23].

2.2 Industry 4.0 - implementation

The process of implementing Industry 4.0 is complex. Transformations can influence the industry as a whole. Studies indicate that organizational challenges are the most important, followed by technological, strategic, financial, security, legal and even ethical challenges [24].

Industries face some barriers such as: high costs in implementing Industry 4.0, lack of knowledge in information technology systems and cybersecurity, privacy and data security issues, and lack of skilled labor for the job, among others [8]. The challenges extend to human resources professionals looking for other professionals in the field related to Industry 4.0 with multidisciplinary skills, to work in positions that require from technical knowledge in the areas of statistics and data analysis to neural networks with artificial intelligence, including behavioral skills, pro activity, creativity, adaptability and initiative [25].

In similar proportions to the challenges in implementing Industry 4.0, so are the opportunities. It is expected by the industry, as well as by its respective executives that with the technologies available, there will be greater control of the production process, it will be possible to carry out performance measurements of the existing process in real time, predict possible future failures in the process, and increase the integration between internal and external areas and processes [8], [9], [11].

At the same time that companies seek to develop their businesses towards the implementation of Industry 4.0, they seek to do it in a sustainable way, and in this process of change, it is important a strategic planning that directs the development of the company [26]. It is also necessary to integrate the new technologies to the existing ones [27] and have clear the operational objectives of the manufacturing and the company that will be the basis for the following decision-making and business development [8]. In addition to the objectives, the understanding of Industry 4.0 concepts and technologies helps in understanding the current state and planning the future state for the intended investment [26].

2.3 Industry 4.0 - retrofit

The term retrofit is used to refer to the process of modernizing or revitalizing some equipment, process or system without mischaracterizing its original elements and objectives [28]. Although some companies have relatively new equipment already with cyber-physical systems incorporated or ready for Industry 4.0, there are many companies that rely on legacy systems that offer no or limited connectivity. In this context, as an option, companies seek retrofit solutions for these systems, in order to modernize them with Industry 4.0 [29].

Economic factors and implementation time are one of the main barriers for companies seeking to implement Industry 4.0 [30]. In this way, the retrofit presents itself as an alternative for the company seeking to reduce investment risks and implementation time [31].

Productivity gains and others are expected for industries that invest in the implementation of Industry

4.0 in their processes, however rare studies address the analysis of technological investment for the implementation of Industry 4.0 in order to assist in decision making on the acquisition of new equipment or realization of retrofit.

3. Method

Given that the objective of the research was to understand the decision-making process for the proposition of a model, this research can be considered qualitative, with the analysis and interpretation of the data made by the researcher, from the particularities to the general [32]. As there are few studies on the subject, the research can be classified as exploratory.

To validate the proposed theoretical model, which was built based on the literature, and to help refine the model, the Delphi method was used, which is characterized by consulting the opinion of experts in successive rounds [33]. In each round, the same version of the model is presented to all experts, and then their considerations are analyzed. When and if necessary, corrections are made and a new version of the model is presented again to the same group of experts for analysis, in a new round.

For the operationalization of the *Delphi* method, a minimum number of five and a maximum of eight experts were defined, as well as a maximum of three rounds of interviews in the search for a consensus for the proposed model with the respective changes suggested in the interview rounds [18].

The technology analysis model was submitted to five experts who contributed with suggestions and criticisms for its improvement. All the experts interviewed worked in the area of Industry 4.0 and innovation for manufacturing processes in the Brazilian industry, having an engineering background and experience in investment decision processes in Industry 4.0. These experts also worked to support cross-functional teams with the same objective, whose characterization is presented in Table 1.

3.1 The questionnaire

The interviews were carried out following an order for the presentation of the content, with an introduction in which the objective and justification of the model was addressed, contextualization of the theme through theoretical reference, details on the applied methodology, and finally, the presentation of the model proposed, in which each of the phases were evaluated, as well as the respective objectives.

After presenting each phase of the model to the experts, the following questions were asked to be answered on a 5-point Likert scale ranging from: (1) Strongly disagree to (5) Strongly agree:

1) The objectives of the stage are clear
2) The stages in which the phases were divided are necessary
3) These stages are sufficient
4) These stages are adequate
5) The flow of these stages allow to reach the objectives of the phase

Finally, we sought to understand from each expert if there were suggestions for changes and if they were in accordance with the main objective of the model proposition, by asking the following questions:

a) Do you suggest any change to refine this phase?
b) Do you suggest any change to refine these stages?

4. Results and Discussion

This study aims to support the management of manufacturing processes in deciding when to acquire new equipment/ processes or when to modernize existing ones to implement Industry 4.0. To this end, the Technology Analysis model – TAM 4.0 was proposed and submitted to experts for refinement.

After applying the *Delphi* method and compiling the results, we reviewed the model according to the suggestions of the experts. Thus, after making the improvements suggested, we reached a final model

Table 1. Characterization of the experts

Expert	Position	Experience (year)	Do you act as an expert in Industry 4.0?
1	Engineer	1	Yes
2	Engineer	8	Yes
3	Engineer	9	Yes
4	Engineer	17	Yes
5	Engineer	22	Yes

that is divided into five phases. Each of the phases of the model has an objective and expected result that aims to support decision-making on technological investment for the implementation of Industry 4.0 in manufacturing processes. Figures 1 and 2 show the finished model.

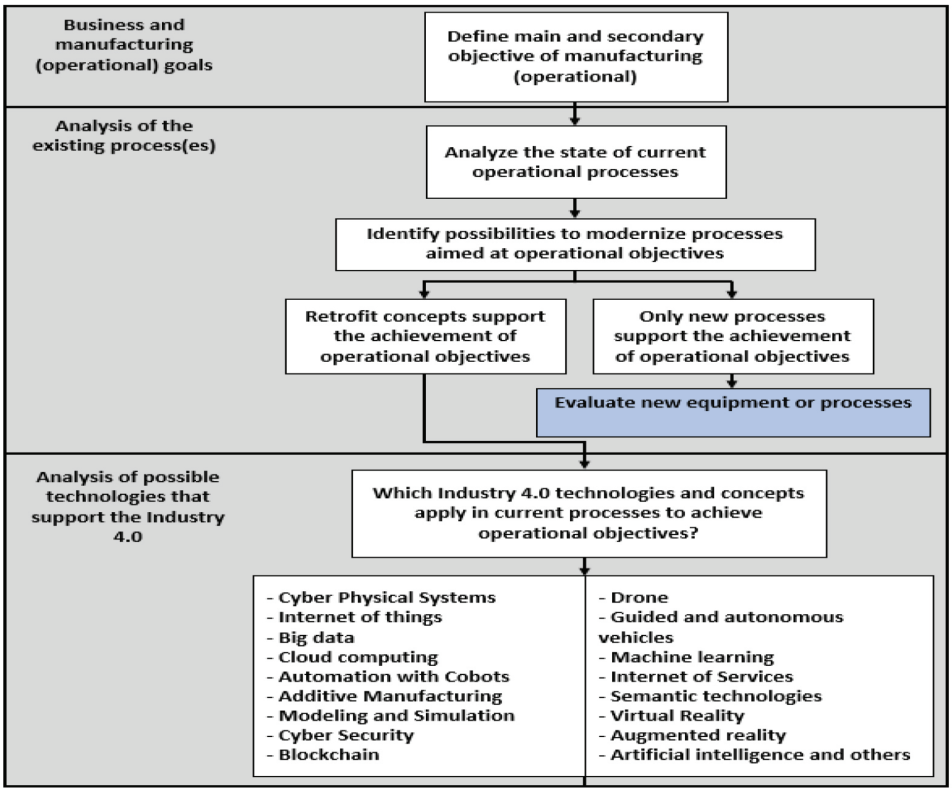

Figure 1. The Technology Analysis model - TAM 4.0 for Industry 4.0 (Part 1/2)

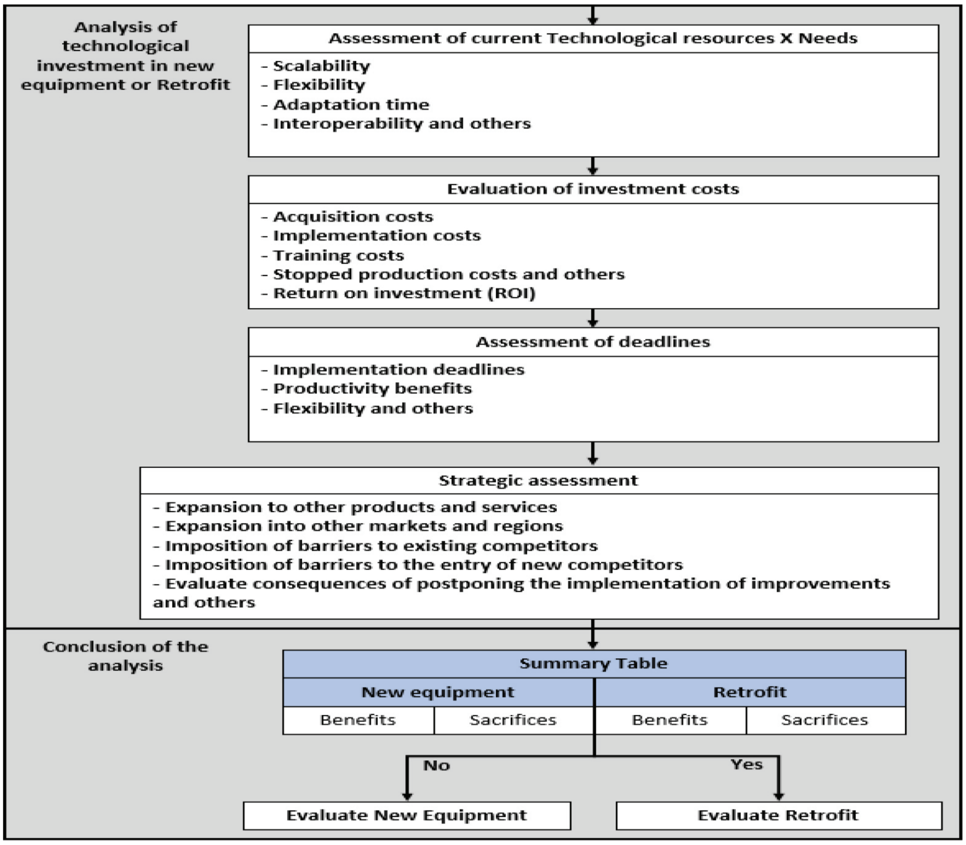

Figure 2. The Technology Analysis model - TAM 4.0 for Industry 4.0 (Part 2/2)

The model was divided into phases for better understanding.

(1) The first phase of the model aims to identify and define the company's objectives and then those of manufacturing (operations). The concept is that after the company's objectives are outlined, the operational objectives are established, in such a way that they are aligned with the company's objectives, so that there can be alignment of the company's strategies with the operations [34].

The main manufacturing objectives are then traced, as well as the secondary ones, to support the main ones [35], in this case the implementation of Industry 4.0, as illustrated in Figure 3.

(2) The second phase of the model proposes the analysis of existing equipment and processes in manufacturing, with the aim of assessing whether existing equipment is subject to modernization/changes (retrofit) or not, in order to achieve manufacturing objectives.

If it is evaluated that they do not allow modernization, the model directs to the evaluation of new equipment and processes. If it is assessed that the existing processes and equipment are subject to modernization, the model continues, always evaluating both the option of acquiring new equipment and processes and retrofitting them, as shown in Figure 4.

(3) In the third phase of the model, it is proposed to analyze the technologies that support the implementation of Industry 4.0, applicable to current manufacturing processes, in order to achieve its objectives. Each of the applicable technologies must be analyzed, its advantages and disadvantages, and how each one can contribute to achieving the manufacturing objectives, and how it can be implemented.

A total of 17 technology areas and themes are presented, allowing the implementation of Industry 4.0 [36], [37] as shown in Figure 5.

In order to keep the model up-to-date and subject to development, in the third and fourth phases, the expression "others" was deliberately left out, allowing these steps to be expanded to new characteristics that can support the development of the decision-making process.

(4) The fourth phase of the model is subdivided into four steps for analysis. It is essential to evaluate each of the steps both for the acquisition of new equipment and processes and for carrying out a retrofit of existing equipment and processes, as shown in Figure 6.

(4.1) The first stage proposes the assessment of current technological resources and their needs for each of the following characteristics: (1) Scalability – for assessing the ability of a process/equipment to adapt to changes in production volume; (2) Flexibility – for analyzing the ability of a process/equipment to adapt to the production of new products and services, or their modifications; (3) Adaptation time

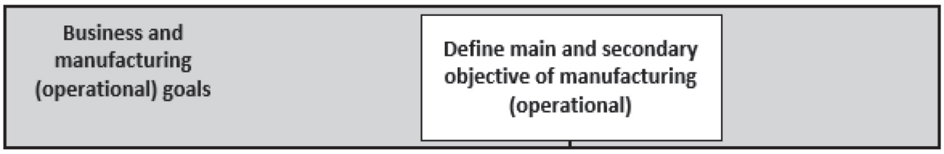

Figure 3. 1st Phase - Identification of the company and operational objectives

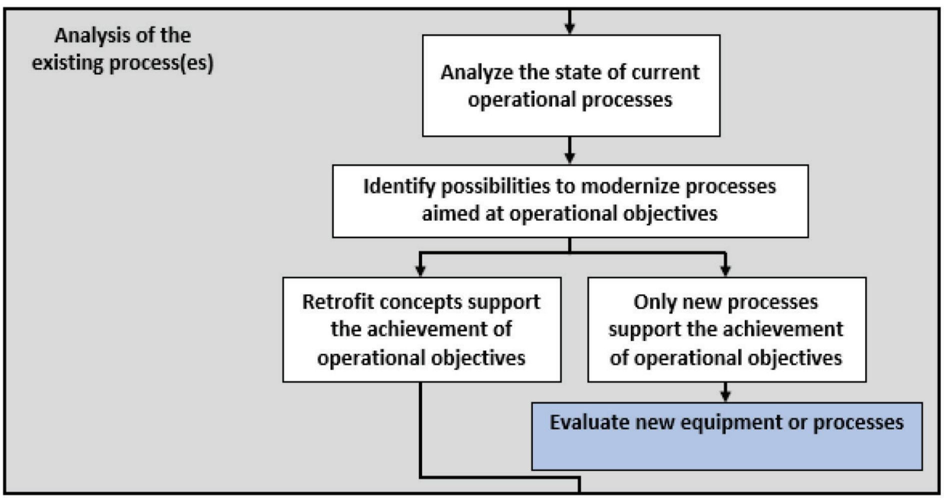

Figure 4. 2nd Phase - Analysis of the existing process(es)

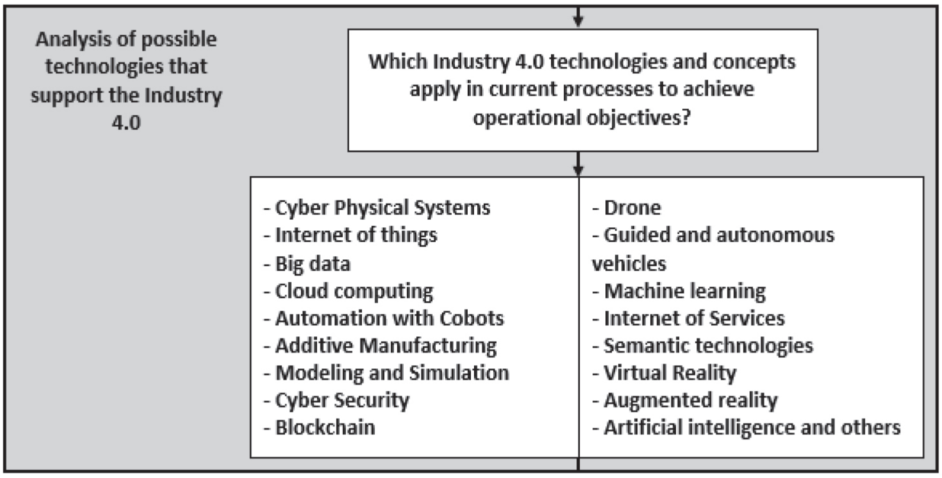

Figure 5. 3rd Phase – Analysis of possible technologies that support Industry 4.0, applicable to current processes

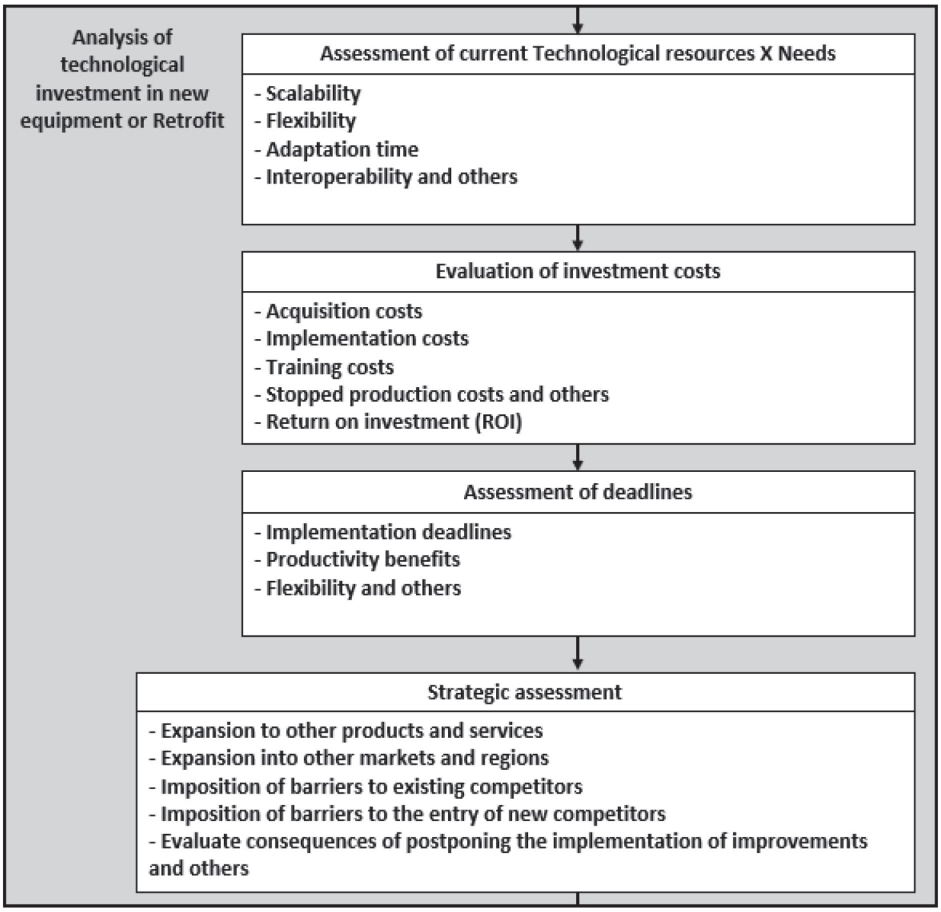

Figure 6. 4th Phase – Analysis of technological investment in new equipment or retrofit

- time required for the process/equipment to adapt to necessary changes; (4) Interoperability – ability of the process/equipment to communicate/integrate with other systems, similar or not [38], [39], and others.

(4.2) The second stage proposes the analysis focused on costs for the investments to be made. For this stage, an analysis is suggested for each of the following considerations: (1) Acquisition costs - includes direct and indirect costs for the acquisition of new processes/equipment or carrying out the retrofit; (2) Implementation costs - involves all the resources needed to operationalize the decision taken; (3) Training costs – includes costs for training the direct and indirect labor necessary to operationalize the processes/equipment; (4) Stopped production costs - direct and indirect costs arising from processes/equipment not operating; (5) Return on Investment - ROI to analyze the return of the investment [40], [41], and others.

(4.3) The third stage proposes a detailed assessment of deadlines, and under the following aspects: (1) Implementation deadlines - time required for implementation; (2) Productivity benefits – expectation of productivity gains with the adopted solution; and (3) Flexibility – versatility expected to achieve operational objectives [8], [42], among others.

(4.4) The fourth stage of this phase proposes the analysis of the operational strategy defined. A detailed analysis is necessary based on the following characteristics: (1) Expansion to other products and services; (2) Expansion into other markets and regions; (3) Imposing barriers to existing competitors; (4) Imposing barriers to the entry of new competitors, and (5) Assessment of the consequences of postponing the implementation of improvements [35], [43], [44], and others.

(5) The fifth and final stage of the model proposes the development of a summary table, placing on one side the condition for acquiring new equipment and processes, and on the other the retrofit condition, with the respective benefits and sacrifices found in the phases prior to this option, in order to assist in decision-making on the acquisition of new equipment or carrying out a retrofit, according to Figure 7.

4.1 Contributions to theory

The Technology Analysis model - TAM 4.0 model brings a new approach beyond models to implement new processes to support Industry 4.0 implementation, or projects related to solve technological problems with the installation of processes / equipment [13], [14].

TAM 4.0 for Industry 4.0 is a contribution to the theory by proposing a model to support the management of manufacturing processes in deciding when to acquire new equipment/ processes or when retrofit them to implement Industry 4.0, including its enabled technologies, as suggested by Medić et al. [15, p.10], and additionally the retrofit approach.

4.2 Contributions to practice

The experts consulted had experience and training in Industry 4.0 and dealt with the acquisition, development and modernization of processes and equipment for the implementation of Industry 4.0. In all the interviews carried out, the experts agreed that in the application of the model, and the participation of multidisciplinary experts is necessary to obtain better results to practice, since the different phases of the model require knowledge about strategic management, technologies, integration between different areas of the company, and others.

These experts were unaware of similar models or the existence of studies that seek to systematize this process, thus considering the pioneering model for these activities. They unanimously agreed on the importance of having a model that guides not only the development of this Industry 4.0 implementation process, but also the approach that contextualizes each of the necessary phases for successful application of Industry 4.0, whether through the acquisition of new processes/equipment or through the retrofit.

5. Conclusion

The objective of this paper was to support the management of manufacturing processes in the decision on when to acquire new equipment and processes, or when to modernize existing ones (retrofit) to implement Industry 4.0 technologies. The Technology Analysis model - TAM 4.0 for Industry 4.0, was proposed based on the scientific literature, and refined by using the *Delphi* method of expert consultation, presenting itself as a new proposition in this line of investigation, scarcely studied, thus being

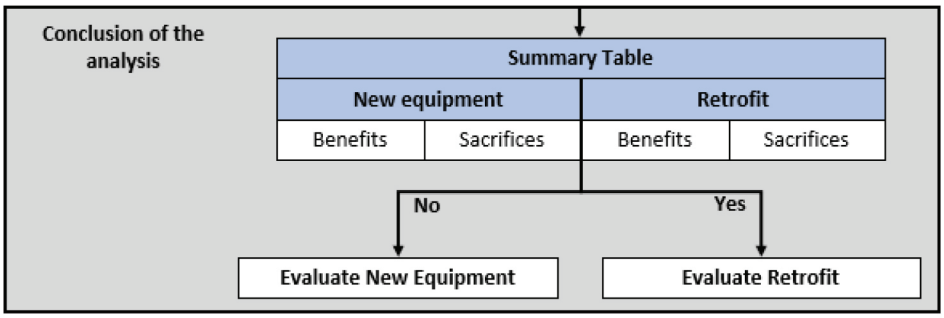

Figure 7. 5th Phase - Conclusion of the analysis

a theoretical contribution to the body of knowledge of Industry 4.0.

Based on the results obtained through the applied methodology, the understanding was unanimous that the decision-making model presents phases that require multidisciplinary knowledge, making it important the participation of those involved who have specific knowledge in the terms addressed for each of the phases.

As a practical contribution, the model supports decision makers to follow a logical and ordered analysis in the process for the decision analysis on the purchase of new equipment/processes or to retrofit them.

As a contribution to society, helping in the implementation project of Industry 4.0, as the model aims, makes it possible to make companies more productive, generating wealth and development, and encouraging people to study to improve themselves to the new reality, thus stimulating the growth of the society.

As a contribution to the environment, the model encourages the analysis of the reuse of existing resources, avoiding spending on raw materials and other means/resources for the manufacture of new equipment and processes, when current ones could be modernized, in accordance with the Sustainable Development Goal #12 Responsible Consumption and Production of the United Nations [45].

As this study is based on academic sources, and due to the small number of experts consulted, from a single country, possibly some steps may not have been considered, a limitation. However, it points out that the model is able to support this analysis.

For future research, it is suggested to submit the model for evaluation to other experts from other countries and compare possible differences in proposal of experts from developed and developing countries, as well as compare differences and similarities proposed by experts from other countries or between continents. It is also suggested to use the model in the field to test its applicability, for its improvement.

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