Disponível em: http://periodicos.ufes.br/BJPE/index

ISSN: 2447-5580

Brazilian Journal of Production Engineering

BJPE - Revista Brasileira de Engenharia de Produção

Campus São Mateus
UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO

ARTIGO ORIGINAL OPEN ACCESS

MÉTODO DE APLICAÇÃO DA INDÚSTRIA 4.0 EM LINHAS DE MONTAGEM AUTOMOTIVAS

METHOD OF APPLICATION OF INDUSTRY 4.0 IN AUTOMOTIVE ASSEMBLY LINES

Cristian Lucas Endler[1], & Pedro Paulo de Andrade Júnior[2*]

[1 2] Departamento de Engenharias da Mobilidade da Universidade Federal Santa Catarina, Rua Dona Franscisca, 8300, Zona Industrial Norte, CEP 89.219-600, Distrito Industrial, Joinville.
[1]cristianendler06@hotmail.com [2]*pp.andrade@ufsc.br

ARTIGO INFO.

Recebido em: 05/06/2019

Aprovado em: 13/06/2019

Disponibilizado em: 05/07/2019

PALAVRAS-CHAVE:

Indústria 4.0; linhas de montagem automotivas; gestão da inovação tecnológica.

KEYWORDS:

Industry 4.0; automotive assembly lines; technological innovation management.

***Autor Correspondente**: Andrade Junior, P.P de.

RESUMO

Atualmente, oberva-se um grande crescimento na aplicação de tecnologias digitais às mais variadas ramificações da indústria. Este fenômeno é chamado de “indústria 4.0” e tende a ser incorporado a todas as indústrias de médio e grande portes em um futuro próximo. Neste panorama, as indústria mais influenciadas são aquelas que fazem maior uso de tecnologias de ponta. O setor produtivo que melhor exemplifica este contexto é o de montagem automotiva. Logo, o presente trabalho tem como objetivo propor um método de aplicação dos conceitos da indústria 4.0 em linhas de montagem automotiva. Em termos metodológicos, foi realizada uma análise bibliométrica para construir um portfólio bibliográfico com alto fator de impacto sobre o assunto. Em seguida, foi realizada a análise sistêmica desse portfólio, extraindo as principais tecnologias-chave da indústria 4.0 para o setor automotivo, as quais são: internet das coisas, máquinas inteligentes, *edge computing*, gêmeos digitais, *big data*, computação em nuvem e sistemas ciber-físicos em manufatura. Como resultado de pesquisa, foi obtida uma metodologia de cinco etapas para a aplicação da indústria 4.0 em empresas de montagem automotiva. Essas etapas são: busca por *know-how* sobre a indústria 4.0, definição de metas e objetivos, treinamento de funcionários, aplicação das principais tecnologias do setor 4.0 e avaliação de resultados / *feedback*.

ABSTRACT

In recent years, a notorious rise of the application of digital technologies to the various ramifications of the industry has been observed. This phenomenon is called "industry 4.0" and tends to be incorporated into all sectors of medium and large-sized industries in the near future. In this panorama, the most influenced industries are those that make greater use of cutting-edge technologies. The industry sector that best exemplifies this context is the automotive assembly sector. The present work has the objective of proposing a method for applying the concepts of industry 4.0 in automotive assembly lines. In methodological terms, a bibliometric analysis was conducted in order to build a bibliographic portfolio with a high impact factor on the subject. Then, the systemic analysis of such portfolio was carried out, extracting the main key technologies of industry 4.0 for the automotive sector, which are: internet of things, machine-learning systems, edge computing, digital twins, big data, cloud manufacturing and cyber-physical systems in manufacturing. As a research result, it was obtained a method that consists of five steps for the application of industry 4.0 in automotive assembly companies. These steps are: search for industry 4.0 know-how, definition of goals and targets, training of employees, application of industry 4.0 key technologies and evaluation of results / feedback.

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

1. INTRODUCTION

In recent years, a notorious rise of the application of digital technologies to the various ramifications of the industry has been observed. This phenomenon is called "fourth industrial revolution" or "industry 4.0" and tends to be incorporated into all sectors of medium and large-sized industries in the near future, due to the competitive advantages and the optimization of the productive and logistic processes provided by the application of such concept (Zhong, Xu, Klotz, & Newman, 2017).

In addition to the real-time operation and migration to the virtual world, the application of industry 4.0 promotes remote assistance, assertive and punctual maintenance and greater production and quality control, in order to synchronize the demand-production binomium.

In this panorama of technological innovation and deep changes in production processes, the most influenced industries are those that make greater use of cutting-edge technologies, due to the competition and the great demand of their customers.

The industry sector that best exemplifies this context is the automotive assembly sector, since this has been submitted to the influence of digital giants in order to control the main technologies of the present and future (Ferràs-Hernández, Tarrats-Pons, & Arimany-Serrat, 2017).

Although some isolated concepts of industry 4.0 are currently applied in automotive assembly lines, studies and methods of integrated industry 4.0 application proposals are still scarce in the academic sector.

Due to this and seeking to meet the perspective of technological demand of the automotive assembly sector through processes of the industry 4.0, we intend to answer the following question: how is it configured a method for application of the concepts of industry 4.0 in automotive assembly lines?

2. EXISTING METHODS FOR THE APPLICATION OF INDUSTRY 4.0 IN AUTOMOTIVE ASSEMBLY LINES

In the study of Jesus (2017) it is proposed to identify the requirements and concepts of industry 4.0, adapting a method for the adoption of these requirements in an automotive company. The method proposed by the author consists of four phases, each phase having a set of individual steps. The phases of the method are, respectively: knowledge, internalization, action and feedback.

The first phase of the method consists of the knowledge of the theme "Industry 4.0" by the automotive sector company. In this period, the employees who will be part of the application team are chosen and the concepts inherent to the industry 4.0 are disseminated to the other employees of the organization.

The second phase of the method proposed by Jesus (2017) consists of internalization, which aims to make clear the organization's involvement in the process of migration to industry 4.0, letting clear the goals of the movement, as well as defining mechanisms to evaluate them.

The third and fourth phases are focused on consolidating the company's strategy, implementing the concepts of industry 4.0 and analyzing the results obtained with it.

After applying the method created to an automotive assembly company, Jesus (2017) found that the same is feasible. The author also concluded that, after the application of the method, the company of the case had elimination in the rework of the components, as well as provided a reduction of 25% in the cycle time, which can be defined as the total time for the execution of the operation on a component.

The consulting firm PwC (2016) has developed a sequence of actions necessary for the application of industry 4.0 precepts in organizations in general. In this method, the first step is to map the company's strategy to industry 4.0. This stage consists of knowing the level of maturity of the company in all levels of the industry 4.0, as well as knowing the impacts of the new applications in the value chain and in the relationship with the customers.

The second phase is to create pilot projects that will help to understand the industry 4.0 approach that will work for the company, even if they do not achieve total success from an economic point of view. After the previous phases, it is necessary to define the trainings that the company needs. Such trainings can take place in four strategic dimensions: organization, people, processes and technology.

The fourth step concerns the fundamental principle of industry 4.0: the data manipulation. It is necessary to develop an own data set based on cross-functional data and connected externally in real time. It is also important to adopt an ideal data analysis platform with a single integrated solution that has the capacity to handle the data trend.

In the fifth step, it is necessary to develop skills related to the development of creative digital strategies, technology architectures, user experience and rapid prototyping capability.

The last phase of the method is based on planning an ecosystem approach. It is substantial a holistic view of the entire process, in order to understand the behavior of the consumer in an effective way, seeing their actions in future ecosystems of partners, customers and suppliers.

The work of Kamble, Gunasekaran & Sharma (2018) aims to analyze the potential barriers that may hinder the application of industry 4.0 in automotive assembly companies. For this purpose, the authors used the technique of Interpretive Structural Modeling (ISM).

The ISM technique aims to analyze complex socioeconomic systems, in the form of a map, showing the interactions between the elements of the system. It is decomposed into several subsystems (or elements) to develop a multilevel, knowledge-based structural model drawn from experts in the research field.

The authors also organized the barriers in order of importance, establishing a level of priority that should be given to each of them. These barriers may be of the managerial scope as well as the technological and scientific scopes, with respect to the automotive industry in question. As barriers in the managerial scope, we can have contractual and legal uncertainties, deep changes in the organizational routine, need for regulatory compliance and higher unemployment rate, due to the increase of process automation.

Among the technological and scientific barriers, we can mention the lack of knowledge management systems in the area of automotive production, the lack of standards and reference architectures in the area, challenges in the integration of production systems and a lack of understanding of the benefits of the industry 4.0.

In sum, it is notable that there are few methods of application of the industry 4.0 in the industrial assembly sector, and even fewer methods aimed at the application of industry 4.0 in the automotive industry. Notwithstanding this scarcity, there is a clear increase in the interest of researchers in the area, due to the growing number of articles published on the subject in recent years.

3. BIBLIOMETRIC AND SYSTEMIC REVIEWS OF INDUSTRY 4.0 TECHNOLOGIES FOR AUTOMOTIVE ASSEMBLY LINES

In order to carry out the bibliometric analysis of the present study, it was decided to use the RIA (Report Article Impact) method, which has the function of selecting articles for the formation of a bibliographic portfolio from high impact periodicals (Andrade Júnior, 2018, in press).

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

After using the RIA method, it was obtained a list of high impact factor publications on the "industry 4.0 in automotive assembly lines" research theme. Among these publications, it can be found from periodical articles to dissertations, theses and manuals of consulting companies. The bibliographic portfolio of high impact factor found is listed in Table 1:

Table 1 - High impact factor bibliographic portfolio.

Publication title	Author (year)
Internet of Things in Industries: A survey	Xu, He e Li (2014)
From Cloud Computing to Cloud Manufacturing	Xu (2012)
Edge Computing: Vision and Challenges	Shi (2016)
Fog and IoT: Na Overview of Research Opportunities	Chiang e Zhang (2016)
Cloud Manufacturing: Strategic Vision and State-of-the-Art	Wu (2013)
Internet of Things for Enterprise Systems of Modern Manufacturing	Bi, Xi e Wang (2014)
A Vision of IoT: Applications, Challenges and Opportunities With China Perspective	Chen (2014)
Current Status and Advancement of Cyber-Physical Systems in Manufacturing	Wang, Törngren e Onori (2015)
A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy and Applications	Lin (2017)
The Evolution and Future of Manufacturing: A review	Esmaeiliana, Behdad e Wang (2016)
Collaborative Manufacturing with Physical Human-Robot Interaction	Cherubini (2016)
Machine Learning for Predictive Maintenance: A Multiple Classifier Approach	Susto (2014)
A Manufacturing Big Data Solution for Active Preventive Maintenance	Wan (2017)
Learning IoT in Edge: Deep Learning for the Internet of Internet of Things with Edge Computing	Li, Ota e Dong (2018)
Machine Learning for Networking: Workflow, Advances and Opportunities	Wang (2017)
Data-Driven Smart Manufacturing	Tao (2018)
A Fog Computing-Based Framework for Process Monitoring and Prognosis in Cyber-Manufacturing	Wu (2017)
Edge Computing for Internet of Things: A Case Study	Premsankar, Francesco e Taleb (2018)
Exploiting Context-Aware Capabilities Over the Internet of Things for Industry 4.0 Applications	Bisio (2018)
Deep Learning for Smart Manufacturinbg: Mehtods and Applications	Wang (2018)
Experimentable Digital Twins - Streamlining Simulation-Based Systems Engineering for Industry 4.0	Schluse (2018)
A Survey of the Advancing use and Development of Machine Learning in Smart Manufacturing	Sharp, Ak e Hedberg Jr. (2018)
Automatic Assembly Simulation of Product in Virtual Environment Based on Interaction Feature Pair	Zhang (2018)
Cloud Manufacturing as a Sustenaible Process Manufacturing Route	Fisher (2018)
Data-Driven Prognostic Method Based on Self-Supervised Learning Approaches for Fault Detection	Wang (2018)
Profile Monitoring Based Quality Control Method for Fused Deposition Modelling Process	He, Zhang e Hong (2018)
Adapting a method for adopting requirements of the industrie 4.0 program: application in a vehicle assemble	Jesus (2017)
Industry 4.0: Digitalization as a competitive advantage in Brazil	PwC (2018)

Source: The authors (2019).

By mapping the systemic variables related to the automotive assembly sector, it is possible to identify the principles of industry 4.0 that are more applicable to the current sector panorama (research results), as well as a projection of future innovations in the area (future recommendations and research gaps) (Table 2).

Table 2 - Systemic analysis table.

Variable	Results, future recommendations and research gaps of the variable
INTERNET OF THINGS Authors who cited the variable: Bisio, Garibotto, Grattarola, Lavagetto,	**Results:** • Internet of Things is the industry 4.0 main technology to make productive processes more efficient; • The integration between Edge Computing and Internet of Things increases the resilience of the system in case of failures; • The key factors for the success of the internet of things application are:

& Sciarrone (2018); Lin, et al., (2017); Chen, Xu, Liu, Hu & Wang (2014); Xu, He & Li (2014); Bi, Xu & Wang (2014).	comprehensive data mining, reliable data transmission and intelligent processing; • Cloud computing is an important factor for the success of the internet of things in the manufacturing sector. **Future recommendations:** • Study on the application of technologies in every layer of the internet of things. Among such technologies, it can be mentioned: wireless sensors, QR code, human-machine interface etc; • Improved intercommunication between devices in IoT; • Homogenization of IoT platforms; • Establishment of regulatory standards in the area; • Use of Service-oriented Architecture (SoA) for the internet of things. **Research gaps:** • IoT data security (confidentiality, integrity and availability); • Difference in flexibility between software and hardware.
MACHINE LEARNING Authors who cited the variable: Li, Ota & Dong (2018); Wang, Ma, Zhang, Gao & Wu (2018); Susto, Schirru, Pampuri, McLoone & Beghi (2014); Tao, Qi, Liu & Kusiak (2018); Sharp, Ak & Hedberg (2018); Wu, et al., (2017).	**Results:** • Use of offloading for performance optimization of machine learning applications in IoT; • Development of a framework for application of MLN (Machine Learning for Networking) on the technological domain; • Development of a methodology for machine learning aiming at predictive maintenance; • Use of Deep Learning to process and analyze the manufacturing Big Data; • Presentation of tools that can be used in deep learning (Theano, Tensorflow, Pytorch etc). **Future recommendations:** • Development of applications for deep learning in complex environments (using edge computing); • Model with greater capacity of generalization to adapt to more extensive circumstances of data dynamics. **Research gaps:** • There is room for MLN network performance improvements, through advances in protocols and architectures; • Low robustness of current machine learning algorithms; • Lack of practical MLN application studies.
EDGE COMPUTING Authors who cited the variable: Lin, et al., (2017); Chiang & Zang (2016); Shi, Cao, Zhang, Li & Xu (2016); Premsankar, Francesco & Taleb (2018).	**Results:** • The use of edge computing generates faster responses to IoT applications; • There must be a complementary relationship between edge computing and cloud computing in order to achieve maximum system efficiency; • Edge computing can reduce IoT system latency time; • Edge computing to meet latency time requirements in virtual reality applications. **Future recommendations:** • Comparison between different edge computing architectures in specific industrial scenarios. **Research gaps:** • Still insufficient speed of data transmission in the cloud for the edge computing demand.
DIGITAL TWINS Authors who cited the variable: Schluse, Priggemeyer, Atorf & Rossman	**Results:** • The use of digital twins to simulate the geometry, structure, data processing and dynamic behavior of physical systems increases the predictability of the behavior of the real system.

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

(2018).	
BIG DATA Authors who cited the variable: Wan, et al., (2017); Tao, Qi, Liu & Kusiak (2018).	**Results:** • Big data can be used to manage the preventive maintenance of manufacturing environments; • Big data lifecycle management method in manufacturing. **Research gaps:** • Heterogeneity of IoT devices.
CLOUD MANUFACTURING Authors who cited the variable: Wu, Greer, Rosen & Shaefer (2013); Esmaeiliana, Behdad & Wang (2016); Fisher, et al., (2018); Xu (2012).	**Results:** • Cloud manufacturing must be customer focused; • The use of cloud manufacturing increases the organization's sustainability; • Key factors for the deployment of cloud manufacturing in the organization: collaborative design, increased automation, increased process resilience and reduced waste. **Future recommendations:** • Cloud manufacturing performance evaluation system; • Cloud manufacturing cost evaluation method.
CYBER-PHYSICAL SYSTEMS IN MANUFACTURING Authors who cited the variable: Wang, Törngren & Onori (2015); Cherubini, Passama, Crosnier, Lasnier & Fraisse (2016).	**Results:** • Simultaneous use of cloud computing, internet of things, big data, additive manufacturing etc. **Future recommendations:** • Methodology for the practical application of cyber-physical systems; • Symbiotic collaboration between humans and robots; • Context-based control. **Research gaps:** • Lack of methods to encompass various domains of cyber physical systems; • Security of cyber-physical systems.
STRATEGY MAPPING FOR INDUSTRY 4.0 Authors who cited the variable: Jesus (2017); PwC (2016).	**Results:** • Knowledge of the maturity level of the company at all levels of industry 4.0; • Know the impacts of new applications in the value chain and in the relationship with customers; • Analysis of requirements and definition of objectives from requirements; • Definition of goal evaluation metrics.
EMPLOYEES TRAINING Authors who cited the variable: Jesus (2017); PwC (2016).	**Results:** • Training should take place in four strategic dimensions: organization, people, processes and technology; • Promotion of internal discussions and dissemination of information material. **Research gaps:** • Little clarification of the tactics used to train employees;
RESULTS ANALYSIS Authors who cited the variable: Jesus (2017).	**Results:** • Collection of data obtained; • Comparison and quantification of results; • Record of difficulties and good practices found in the first phase of implementation of the industry 4.0.

Source: Authors (2019).

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

Due to the fact that the systemic analysis is supported by a bibliometric review of periodicals with a high impact factor, it can be concluded that the variables found in Table 2 constitute the principles of industry 4.0 with greater applicability in automotive assembly lines.

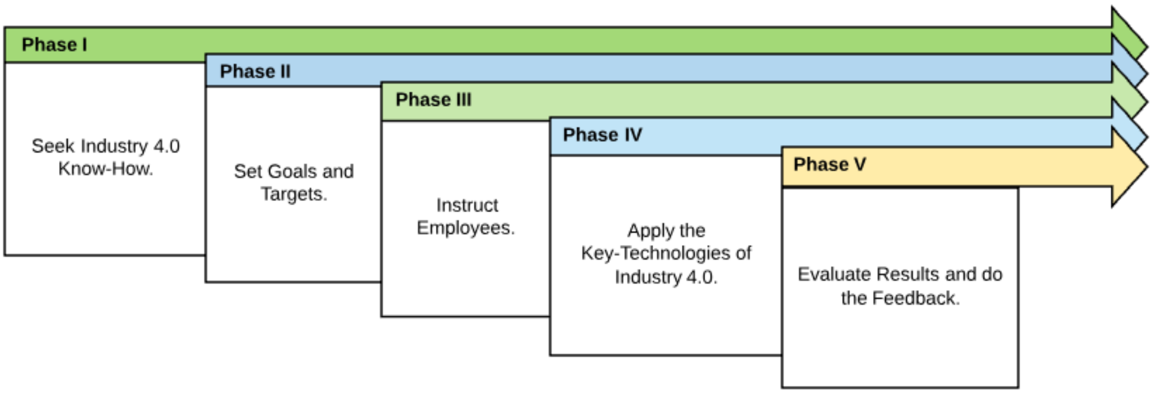
These principles are: internet of things, machine learning, edge computing, digital twins, big data, cloud manufacturing and application of cyber-physical systems in manufacturing.

4. PROPOSED METHOD

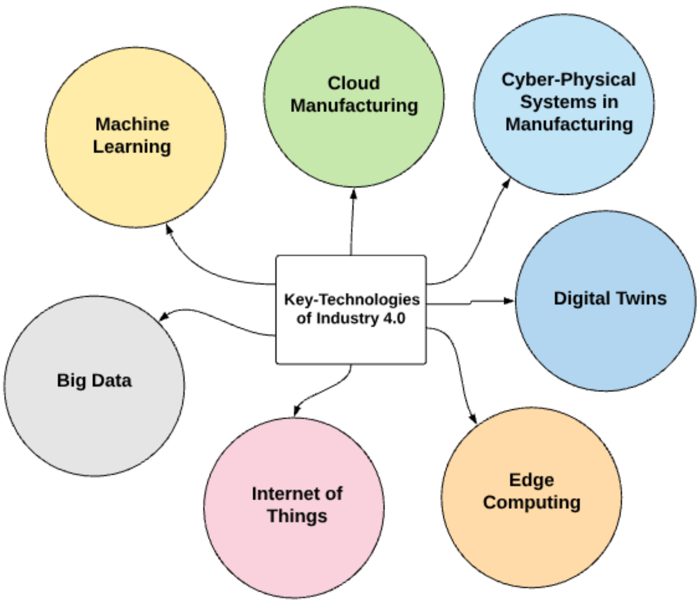
4.1. INITIAL CONSIDERATIONS ON THE METHOD

The method of application of the industry 4.0 concepts in automotive assembly lines can be represented by the following frameworks:

Figure 1 - (a) Framework of the proposed method; (b) Key-technologies applied in the phase four of the method.



(a)



(b)

Source: Authors (2019).

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

The proposed method is subdivided into five basic phases. It is important to note that, as you move from one phase to another, not necessarily the previous phase needs to cease.

The method is an adaptation of the best aspects of the existing methods in literature, with the addition of identifying the main key technologies of industry 4.0 for the automotive assembly sector.

4.2. CHARACTERIZATION OF THE PROPOSED METHOD

The basic steps of the present method are: 1) Search for industry 4.0 know-how; 2) Definition of goals and targets; 3) Training of employees; 4) Application of industry 4.0 key technologies and 5) Evaluation of results and feedback.

The five basic steps presented constitute an infinite loop, that is, the method proposed here aims at the continuous improvement of the organization within the industry 4.0.

4.2.1. SEARCH FOR INDUSTRY 4.0 KNOW-HOW

The first step is the search for industry 4.0 know-how. This search should be conducted by the managers of the organization and can rely on the service of consulting companies, in order to facilitate the process. In this step, it is necessary to obtain knowledge of the key mechanisms and technologies of industry 4.0, as well as to know the experience of organizations that have already implemented it in their productive processes.

The search for knowledge by theme must come from a variety of sources, from success stories already registered to academic journals of high impact factor. Due to the multidisciplinary character of the industry 4.0, the team that will take this initial step should be composed of managers from different areas of the organization (manufacturing, product engineering, marketing, people management, purchasing, sales, among others).

In an application of this method in the near future, it is recommended to prioritize the key technologies cited in figure 2. Despite this, it is important at this point to express the fact that the key technologies listed in figure 2 constitutes the quintessence of industry 4.0 only at the present time.

4.2.2. DEFINITION OF GOALS AND TARGETS

Managers must clearly define the desired goals with the adoption of industry 4.0 in the organization. The objectives of the organization can be of different scopes, such as the feasibility of incorporating a certain characteristic to the product, reduction of the lead-time,

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

reduction of production costs in the medium or long term, strengthening the image of the company, increase of the environmental sustainability of the production process, among others.

If possible, the objectives should be quantitative in order to facilitate the evaluation of the results of the application of the industry 4.0, which is the fifth step of this method.

4.2.3. TRAINING OF EMPLOYEES

The knowledge obtained in the first stage of the method must be disseminated to all employees that are involved, directly or indirectly, in the productive context.

This dissemination of knowledge can be conducted by managers or contracted consulting and training companies. The exchange of knowledge can take place through lectures, forums, participation in specific events or trainings. It is also interesting to use information material, which can be distributed by e-mail, communication panels, intranet, among others.

At this stage, it is of great importance that all the employees of the organization are committed to the objectives of the application of the industry 4.0, because, in order to reach full efficiency, a change in the organizational culture is also necessary, as in other previous industrial revolutions of the history.

4.2.4. APPLICATION OF INDUSTRY 4.0 KEY-TECHNOLOGIES

After the search for know-how, the definition of organizational goals and the training of employees, the organization will be ready to apply the industry 4.0 key technologies to the automotive assembly line. These technologies are, according to Table 2: internet of things, machine learning, edge computing, digital twins, big data, cloud manufacturing and application of cyber-physical systems in manufacturing.

It is necessary to reiterate that the aforementioned technologies are the state of the art of industry 4.0 for the automotive assembly industry only at the present time. If this method is applied over the years, it will be of substantial relevance to conduct new bibliometric and systemic analyzes in order to express the most recent concepts on the subject.

In order to achieve an efficient application, it is necessary to involve employees at all hierarchical levels of the company in order to identify the points of the production line that most need the technological mechanisms of industry 4.0, as well as the intensity of application.

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

Through the systemic analysis conducted in section 3, it was possible to identify good practices in the application of the industry 4.0 key technologies. Important features of the application of these technologies are illustrated in Table 3:

Table 3 - Characteristics to be followed in the application of the key technologies.

Key Technology	Characteristics to be followed in the application of the key technologies
INTERNET OF THINGS	• Data extraction for the IoT should be broad, using state-of-the-art devices such as Wireless sensors, QR Code etc; • IoT should be applied in conjunction with Edge Computing in order to increase resilience to system failures; • The transmission of data must be reliable and the processing must be done in an intelligent way, aiming to increase the efficiency of the productive process, through the reduction of waste.
MACHINE LEARNING	• Frameworks can be used for the application of this key technology, as the proposed by Wu et al. (2017), for example; • One of the biases of systems with machine learning should be related to the predictive maintenance of the machines, in order to reduce production costs and increase the efficiency of the production process; • Commercial tools, such as Theano, Tensorflow and Pytorch are of great value for the programming and management of intelligent systems.
EDGE COMPUTING	• Edge Computing should be applied in conjunction with all other industry 4.0 technologies so that the systems can achieve maximum efficiency by reducing the latency time.
DIGITAL TWINS	• The concept of digital twins should be applied to increase the predictability of real systems, through the simulation of their geometry, structure or dynamic behavior; • Applicability centered on the pre-project of the production line 4.0 or in case of change of the existing parameters of the production line machines.
BIG DATA	• Big Data must be used to manage the preventive maintenance of production line machinery, based on continuous operation reports of the machines.
CLOUD MANUFACTURING	• The application of Cloud Manufacturing in the production line should be based on the following factors: collaborative design, general increase of the level of automation, increase of resilience to process failures and reduction of waste.

Source: The Authors (2019).

The application of industry 4.0 technologies will become better adapted to the organizational context at each iteration of the method. After this application, it is necessary to evaluate the results obtained, followed by the feedback of the method.

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

4.2.5. EVALUATION OF RESULTS AND FEEDBACK

In this step it is necessary to compare the before and after of the variables related to the objectives stipulated in step 2 of the method, that is, it is necessary to evaluate or measure the gain in lead time, reduction of production costs, increase of the environmental sustainability of the productive process or in another stipulated goal.

It is also necessary to list the successes and errors made in this first cycle of the method. Thus, it ensures that mistakes will no longer be made in the course of the application of industry 4.0 in the organization.

After the completion of the fifth step, the feedback process is performed, that is, it returns to step 1 with the lessons learned in the first cycle of application. This leads to continuous improvement of the assembly line.

The method must be iterated cyclically in the organization in order to remove the errors and increase the efficiency of the process as a whole.

5. CONCLUSIONS

The present study consisted in proposing a new method of application of the concepts of industry 4.0 in automotive assembly lines. Firstly, a theoretical basis was elaborated in order to provide a better knowledge of the basic concepts of the fourth industrial revolution.

Then, bibliometric and systemic reviews were conducted on the subject, with the purpose of exposing the main key technologies of industry 4.0 for automotive assembly lines.

In the systemic analysis of the bibliographic portfolio, a set of articles was studied in detail, extracting the key technologies of industry 4.0 that compose this method.

The proposed method consisted of five basic steps: search for industry 4.0 know-how, definition of goals and targets, training of employees, application of key technologies and evaluation of results and feedback.

Practices necessary for the implementation of the key technologies were explained, based on the bibliographic portfolio of high impact factor. We also presented the critical factors for the success of this tool, as well as it´s delimitation.

The method, in the exact manner in which it appears, is applicable specifically to automotive assembly lines. However, the same can be generalized to other areas of the industry if some changes are made.

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

The method developed has several opportunities for improvement. Such opportunities may become more sensitive if applied in a real case study. Project management tools can also be incorporated to make the method more robust and easier to apply.

It is also interesting to study the labor consequences for employees involved in this paradigm shift, evaluating how their workforce will be affected and how the people management sector should proceed in terms of professional retraining of the employees.

References

Ahuett-Garza, H., & Kurfess, H. (2018). A brief discussion on the trends of habilitating technologies for industry 4.0 and smart manufacturing. *Manufacturing Letters*, *15*(b), 60-63. doi:10.1016/j.mfglet.2018.02.011

Andrade Júnior, P. P. (n.d.). *Método RIA: seleção de artigos para formação de um portfólio bibliográfico a partir de periódicos de alto fator de impacto*. In press.

Bi, Z., Xu, L., & Wang, C. (2014). Internet of things for enterprise systems of modern manufacturing. *Ieee transactions on industrial informatics*, *10*(2), 1537-1546. doi:10.1109/TII.2014.2300338

Bisio, I, Garibotto, C., Grattarola, A., Lavagetto, F., & Sciarrone, A. (2018). Exploiting context-aware capabilities over the internet of things for industry 4.0 applications. *Ieee network*, *32*(3), 108-115. doi:10.1109/MNET.2018.1700355

Chen, S., Xu, H., Liu, D., Hu, B., & Wang, H. (2014). A vision of iot: applications, challenges, and opportunities with china perspective. *Ieee internet of things journal*, *1*(4), 349-359. doi:10.1109/JIOT.2014.2337336

Cherubini, A., Passama, R., Crosnier, A., Lasnier, A., & Fraisse, P. (2016). Collaborative manufacturing with physical human–robot interaction. *Robotics and computer-integrated manufacturing*, *40*, 1-13. doi:10.1016/j.rcim.2015.12.007

Chiang, M., & Zhang, T. (2016). Fog and IOT: an overview of research opportunities. *Ieee internet of things journal*, *3*(6), 854-864. doi:10.1109/JIOT.2016.2584538

Esmaeiliana, B., Behdad, S., & Wang, B. (2016). The evolution and future of manufacturing: a review. *Journal of manufacturing systems*, *39*, 79-100. doi:10.1016/j.jmsy.2016.03.001

Ferràs-Hernández, X., Tarrats-Pons, E., & Arimany-Serrat, N. (2017). Disruption in the automotive industry: a cambrian moment. *Business horizons*, *60*(6), 855-863. doi:10.1016/j.bushor.2017.07.011

Fisher, O, Watson, N., Porcu, L., Bacon, D., Rigley, M., & Gomes, R.L. (2018). Cloud manufacturing as a sustainable process manufacturing route. *Journal of manufacturing systems*, *47*, 53-68. doi:10.1016/j.jmsy.2018.03.005

He, K., Zhang, Q., & Hong, Y. (2018). Profile monitoring based quality control method for fused deposition modeling process. *Journal of intelligent manufacturing*, *30*(2), 1-12. doi:10.1007/s10845-018-1424-9

Jesus, R.A. *Adaptação de um método para adoção de requisitos do programa industrie 4.0: aplicação em uma montadora de veículos*. Master degree, universidade metodista de piracicaba, santa bárbara d´oeste, 2017.

Kamble, S. S., Gunasekaran, A.A, & Sharma, R. (2018). Analysis of the driving and dependence power of barriers to adopt industry 4.0 in indian manufacturing industry. *Computers in industry*, *101*, 107-119. doi:10.1016/j.compind.2018.06.004

Li, H., Ota, K., & Dong, M. (2018). Learning IOT in edge: deep learning for the internet of things with edge computing. *Ieee network*, *32*(1), 96-101. doi:10.1109/MNET.2018.1700202

Lin, J., Yu, W., Zhang, N., Yang, X., Zhang, H., & Zhao, W. (2017). A survey on internet of things: architecture, enabling technologies, security and privacy, and applications. *Ieee internet of things journal*, *4*(5), 1125-1142. doi:10.1109/JIOT.2017.2683200

Minoli, d., Sohraby, K., & Occhiogrosso, B. (2017). IOT considerations, requirements, and architectures for smart buildings—energy optimization and next-generation building management systems. *Ieee internet of things journal*, *4*(1), 269-283. doi:10.1109/JIOT.2017.2647881

Monostori, L., Kádár, B., Bauernhansl, T, Kondoh, S., Kumara, S., Reinhart, G., Sauer, O., Schuh, G., Sihn, W., & Ueda, K. (2016). Cyber-physical systems in manufacturing. *Manufacturing technology*, *65*(2), 621-641. doi:10.1016/j.cirp.2016.06.005

Pandey, A., & Pradhan, S. K. (2018). Investigations into complete liquefier dynamics and optimization of process parameters for fused deposition modeling. *Materials today*, *5*(5), 12940-12955. doi:10.1016/j.matpr.2018.02.279

Citação (APA): Andrade Junior, P.P de, & Endler, C.L. (2019). Method of application of industry 4.0 in automotive assembly lines. *Brazilian Journal of Production Engineering*, *5*(3), 104-119.

Premsankar, G., Francesco, M., & Taleb, T. (2018). Edge computing for the internet of things: a case study. *Ieee internet of things journal*, 5(2), 1275-1284. doi:10.1109/JIOT.2018.2805263

Pwc. (2016). *Industry 4.0: digitalization as a competitive advantage in Brazil*. Retrieved July 1, 2018, from https://www.pwc.com.br/pt/publicacoes/servicos/assets/consultoria-negocios/2016/pwc-industry-4-survey-16.pdf

Schluse, M.L., Priggemeyer, M., Atorf, L., & Rossman, J. (2018). Experimentable digital twins—streamlining simulation-based systems engineering for industry 4.0. *Ieee transactions on industrial informatics*, *14*(4), 1722-1731. doi:10.1109/TII.2018.2804917

Sharp, M., Ak, R., & Hedberg Junior, T. (2018). A survey of the advancing use and development of machine learning in smart manufacturing. *Journal of manufacturing systems*, *48*(c), 115-136. doi:10.1016/j.jmsy.2018.02.004

Shi, W., Cao, J., Zhang, Q., Li, Y., & Xu, L. (2016). Edge computing: vision and challenges. *Ieee internet of things journal*, *3*(5), 637-646. doi:10.1109/JIOT.2016.2579198

Susto, G. A., Schirru, A., Pampuri, S., McLoone, S., & Beghi, A. (2014). Machine learning for predictive maintenance: a multiple classifier approach. *Ieee transactions on industrial informatics*, *11*(3), 812-820. doi:10.1109/TII.2014.2349359

Tao, F., Qi, Q., Liu, A., & Kusiak, A. (2018). Data-driven smart manufacturing. *Journal of manufacturing systems*, *48*(c), 130-139. doi:10.1016/j.jmsy.2018.01.006

Wan, J., Tang, S., Li, D., Wang, S., Liu, C., Abbas, H., & Vasilakos, A. (2017). A manufacturing big data solution for active preventive maintenance. *Ieee transactions on industrial informatics*, *13*(4), 18-27. doi:10.1109/TII.2017.2670505

Wang, J., Ma, Y., Zhang, L., Gao, R.X., & Wu, D. (2018). Deep learning for smart manufacturing: methods and applications. *Journal of manufacturing systems*, *48*(c), 128-132. doi:10.1016/j.jmsy.2018.01.003

Wang, T., Qiao, M., Zhang, M., Yang, Y., & Snoussi, H. (2018). Data-driven prognostic method based on self-supervised learning approaches for fault detection. *Journal of intelligent manufacturing*, p. 26-38. doi:10.1007/s10845-018-1431-x

Wang, M., Cui, Y., Wang, X., Xiao, S., & Jiang, J. (2017). Machine learning for networking: workflow, advances and opportunities. *Ieee network*, *32*(2), 92-99. doi:10.1109/MNET.2017.1700200

Wang, L., Törngren, M., & Onori, M. (2015). Current status and advancement of cyber-physical systems in manufacturing. *Journal of manufacturing systems*, *37*(2), 517-527. doi:10.1016/j.jmsy.2015.04.008

Wu, D., Greer, M.J., Rosen, D.W., & Shaefer, D. (2013). Cloud manufacturing: strategic vision and state-of-the-art. *Journal of manufacturing systems*, 32(4), 564-579. doi:10.1016/j.jmsy.2013.04.008

Wu, D., Liu, S., Zhang, L., Terpenny, J.P., Gao, R.X., Kurfess, T., & Guzzo, J.A. (2017). A fog computing-based framework for process monitoring and prognosis in cyber-manufacturing. *Journal of manufacturing systems*, *53*(1), 25-34. doi:10.1016/j.jmsy.2017.02.011

Xu, L., He, W., & Li, S. (2014). Internet of things in industries: a survey. *Ieee transactions on industrial informatics*, 10(4), 2233-2243. doi:10.1109/TII.2014.2300753

Xu, X.. (2012). From cloud computing to cloud manufacturing. *Robotics and computer-integrated manufacturing*, *28*(1), 75-86. doi:10.1016/j.rcim.2011.07.002

Zhang, J., Wang, P., Zuo, M., Li, Y., & Xu, Z. (2018). Automatic assembly simulation of product in virtual environment based on interaction feature pair. *Journal of intelligent manufacturing*, *29*(6), 1235-1256. doi:10.1007/s10845-015-1173-y

Zhong, R.Y., Xu, X., Klotz, E., & Newman, S.T. (2017). Intelligent manufacturing in the context of industry 4.0: a review. *Engineering*, *3*(5), 616-630. doi:10.1016/J.ENG.2017.05.015