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Thematic Section - Production Engineering leading the Digital Transformation

A Production System for the auto parts industry with elements of Industry 4.0

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Abstract

Paper aims: considering that the fourth industrial revolution can be a primary engine for process innovation, this research proposes a 4.0 Production System applicable to the auto parts industry.

Originality: the study's relevance is observed from the assimilation of practical issues with the scientific process for constructing a 4.0 Production System for the sector in question.

Research method: this research is structured from a real case study, proposing an artifact from Design Science Research.

Main findings: the results obtained provided a competitive advantage to the company, with a reduction of 23% in lead time, 16% in HM/Fuel Tank, 55% in WIP, and 38% in the total distance traveled by operators, in addition to an ROI of 9.22%.

Implications for theory and practice: the practical application of the artifact showed that its use is viable; however, to extract the maximum potential, it is suggested to insert it into the company's culture.

Keywords

Mass production. Toyota Production System. Volvo Production System. Hyundai Production System. Operational Performance.

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1. Introduction

Although an automobile comprises several components, only a few are manufactured by automakers. The vast majority, such as engines, suspensions, transmissions, and components, are generally supplied by specialized manufacturers, known as auto parts industries. In the automobile industry, competition among assemblers unfolds throughout the entire production chain, which reflects in demands for cost reduction, shortening product development time, and the search for innovation in products and processes (Garo Júnior & Guimarães, 2018). Therefore, one of the relevant factors in this medium is operational efficiency.

However, operational efficiency does not present competitive advantages but is required for industries to enter the market. Thus, it is mandatory to search for new management routines and improvements to maintain products with satisfactory quality levels at affordable costs and deadlines. To meet this requirement, developing a flexible, intelligent, and modernized production system is recommended to complete a more personalized demand on the same production line (Lasi et al., 2014). Consequently, flexible manufacturing and rapid delivery are the new design techniques that meet these challenges (Porter & Heppelmann, 2015).

In this sense, the success of manufacturing depends on the evolution of new business models supported by new technologies (Esmaeilian et al., 2016). Historically different production models (mass production, Lean Production, the human-centered reflective model) have already been developed (Clarke, 2005), and recently another model has gained relevance, the modularized and automated production model (Nunes et al., 2017). Therefore, the fourth industrial revolution (Industry 4.0) is modifying the manufacturing industry, intensifying the competitiveness between organizations (Lasi et al., 2014; Goecks et al., 2020) based on the availability of several technologies with new interfaces for communication (Prinz et al., 2016). The hallmark of this revolution is the fusion of technologies that cross the boundaries between the physical, biological and digital, bringing challenges to all businesses and opening unprecedented opportunities for innovation (Schwab, 2017).

When considering technological advances in the manufacturing industry and their implications for business processes, there is a need to experiment with new management models. Given the models presented, there is no ideal production system for each case, as each company has its peculiarities to be evaluated (Clarke, 2005). Thus, the different existing production systems work as guides for the conception or restructuring of a new system (Shingo, 1988). In this sense, Tascón et al. (2022) present new directions regarding adopting Industry 4.0 technologies and how to customize them for the realities of emerging countries.

Lean thinking has proved to be a success in the face of mass production practices. In contrast, Industry 4.0 has become an essential strategic approach to technological change from traditional manufacturing, connecting the physical with the digital (Bittencourt et al., 2020). The transformation of traditional manufacturing methods into intelligent processes it is a topic to be explored worldwide. Industry 4.0 proposes advancing manufacturing with reduced product life cycles and mass customization (Shi et al., 2020). Mabkhot et al. (2018) reinforce that the introduction of other elements in traditional manufacturing systems enables the development of intelligent systems (Smart Factory), enhancing the company's competitiveness, such as the incorporation of Industry 4.0 Technologies studied in this research.

Skills in Production Engineering can contribute with technical knowledge to the digital transformation and structuring of a new production system (Bischof-dos-Santos & Oliveira, 2020). Engineering actions can reduce costs for each company according to particularities, microeconomic context, and production strategy. Considering that the fourth industrial revolution can be a primary driver for process innovation, the following research question emerges: how structure a production system for the auto parts industry, based on existing systems and Industry 4.0, to improve your production process?

This research proposes a method for implementing a Production System for the auto parts industry with Industry 4.0 elements identifying the best practices of existing models allowing to design Industry 4.0 as a production system conceptual model for the auto parts industry. The present study is structured from section 1, presenting the research problem context and objectives. Section 2 provides a background on production systems. Section 3, methodology, anchored the structure of how this research was developed. Finally, in sections 4 and 5, respectively, the results achieved from this research and the analysis and discussions of these.

2. Production Systems and Industry 4.0

Receiving system inputs and transforming them, through organized processes, into results (system outputs). The production system can be understood as a group of interrelated components that work together toward achieving a common goal. Among unique production systems in the industry's history, we can mention the Production Systems: Mass Production, Toyota, Volvo, and Hyundai.

The evolution of production systems began with Artisanal Production, later advancing to Mass Production. In Artisanal Production, workers were highly qualified and used only simple tools to produce personalized products, reducing production volume without standardization. Faced with the need for the evolution of this system, where the demand for products was growing, Mass Production emerged (idealized by Ford). Specialized professionals designed standardized products manufactured in significant quantities by unskilled or semi-skilled workers, operating expensive equipment for specific purposes. In this system, the idle time was avoided concerning the machinery's high cost, with the use of stocks and extra workers to guarantee the availability of inputs so that the production flow is not slowed down. Due to the high cost of investment in machines, adaptation to the manufacture of new products is impeded, and the consumer benefits from low prices at the expense of variety (Womack et al., 1990).

However, this model declined due to social and economic changes, reduced productivity and quality indices, and increased production costs. In this way, it opened space for oriental companies that stood out for using the intellectual capacity of the company's employees, gaining in quality, cost, and reduction of sales cycles, thus giving rise to the TPS - Toyota Production System (Martin et al., 1994). This one had the contribution of renowned experts (Taiichi Ohno, Shigeo Shingo, and Eiji Toyoda) to provide productivity gains by combating excess production and, consequently, the waste generated in the production environment. It was producing just the right components in the right place at the right time and leading to a reduction in inventories, costs, and improvement in product quality (Ohno, 1988). This system can be achieved by identifying and mitigating Lean

Manufacturing barriers, changing the organization's culture, integrating the supply chain, and innovating and adapting (Bhamu & Singh Sangwan, 2014).

However, creating superior global systems is necessary, which requires adapting elements from one production system to another. In this scenario, the Volvo Production System (VPS) was designed, which uses methods that simplify operations and minimize productivity losses. The VPS provides principles, tools, and guidelines on how the entire Volvo production network must work, aiming at the pursuit of operational excellence to achieve the best performance in six competitive priorities, abbreviated as SQDCEP: Security, Quality, Delivery, Cost, Environment, and People (Netland, 2013). Furthermore, the VPS is structured on five principles: (i) teamwork; (ii) process stability; (iii) Built-in-Quality – BIQ; (iv) continuous improvement; and, (v) Just-in-Time (Netland & Sanchez, 2014).

Due to constant strikes and demands from employees and unions, Hyundai was forced to seek new competitive strategies, develop a technological approach, and minimize process dependence on workers (Chung, 2002). In response to this problem, production modularization was developed. Even after attempting to implement the TPS, Hyundai realized that it was necessary to reinterpret it according to its own needs. It can be considered as a process with the support of suppliers, research institutes, and universities (Wallace, 2004), associated with the expansion of production capacity and technology-oriented innovations (Chung, 2002). In this new strategy, workers operate the production lines without involvement and commitment to the improvement process. Production processes are now made centrally by the factory managers and the responsible engineers (Lee & Jo, 2007). According to Chung (2002), the principles of the Hyundai Production System (HPS) are: (i) technology and engineering-oriented to process automation; and (ii) modularization – Just In Sequence.

2.1. Industry 4.0

The first industrial revolution, which started in England (1760 to 1840), instigated by the construction of railways and the arrival of steam engines, was characterized by the beginning of mechanical production. The second revolution (between the end of the 19th century and the beginning of the 20th century) introduced electricity, steel, petrochemicals, new processes in production lines, and the concepts of international enterprise and mass production. The third revolution (from the 1960s), called the digital revolution, was driven by the development of semiconductors and the internet, the use of electronics, robotics, telecommunications, in addition to the globalization and expansion of financial capitalism, making the processes of complex, automatic and sustainable manufacturing (Wahlster, 2012; Qin et al., 2016; Schwab, 2017).

In this scenario, the industry peaked at serial and standardized production. The initiative sought new processes that brought simplification and training to meet this customized demand (Wahlster, 2012). Digital technologies caused the rupture of the third industrial revolution with new technological resources (Schwab, 2017). Thus, a new concept, Industry 4.0, was introduced in Germany during the Hannover fair (2011), formalizing the beginning of the Fourth Industrial Revolution (Xu et al., 2018). This theme emphasizes that manufacturing will exchange information between machines and production units, acting autonomously and intelligently in interoperability (Qin et al., 2016). Currently, digital production has actively participated in production systems. For this reason, production systems in Industry 4.0 have unique characteristics, which bring new challenges and requirements for modeling and analysis (Long et al., 2016).

Given special attention to the Ford, Volvo, Toyota, Hyundai, and Industry 4.0 systems, this research presents the differences between each one (Table 1), and also performs a critical analysis of these systems.

A very recent and essential trend is combining and connecting production systems with technologies to make production highly flexible and efficient (Porter & Heppelmann, 2015). Industry 4.0 is one possible approach to achieving these goals. This trend can also be observed worldwide (Long et al., 2016). More traditional techniques focus on product flow and how production elements are organized. The most modern approaches value the importance of flexibility in the organization of processes, benefiting from advances in new technologies to meet increasingly individual demands (Nof, 2013).

Industry 4.0 stands out as an intelligent manufacturing system allowing for operations automation and even inclusion in products, favoring autonomous operation and with little human influence. By integrating the concepts of production systems with Industry 4.0 technologies, the Smart Factory context is enhanced. According to Osterrieder et al. (2020), the Smart Factory concept can be defined as a future state of a fully connected manufacturing system, generating, transferring, receiving, and processing the data necessary to perform all the tasks required for the production of all types of products. They contribute to improving manufacturing processes' performance, quality, controllability, management, and transparency (Shi et al., 2020).

Table 1. Critical analysis of production systems.

Elements	Ford	Toyota	Volvo	Hyundai	Industry 4.0
Known as	Fordism / Mass	Toyotism / Lean	Volvisism/ Reflective / Socio-technical	Hyundaism / Modularization	Advanced Manufacturing / Smart Manufacturing
Mechanization	High	Medium	Medium	High	High
Engineering	Important	Important	Important	Priority	Priority
Workforce	Specialists	Specialists and Generalists	Specialists and Generalists	Specialists	Specialists
Standardization	High	Medium	Medium	High	High
Management	Pushed	Pulled	Pulled	Pushed	-
Flexibility	Low	High	High	High	High
Ergonomics	No	Yes	Yes	No	Yes
Improvement	Leaders	All involved	All involved	Engineers	Specialists
Operator autonomy	Low	Medium	High	Low	Low
Product modularization	No	No	No	Yes	Yes
Employee appreciation	Low	High	High	Low	Medium
Suppliers relationship	Multiple suppliers and choice by cost	Long term and synergistic	Long term and synergistic	Short term and focus on cost reduction	Short term and focus on cost reduction
System principles	Low cost and high production	JIT e Autonomation	Reflective and socio-technical	Automation-oriented modularization and engineering	Smart Factories and Products

3. Method

This study's classification is developed from a real case study of an applied nature. The research method was Design Science Research (DSR) to create the artifact that solves the problem in question. DSR is a method that bases and operationalizes research that aims to propose artifacts or a prescription oriented to problem-solving. Once the problem is understood, the construction and evaluation of artifacts occur, causing them to change the observed reality, solve the practical problems, or improve the system's performance (Goecks et al., 2021). Furthermore, it allows evaluating what was projected with the result obtained (Kuechler & Vaishnavi, 2011). Figure 1 presents the method proposed by Kuechler & Vaishnavi (2011) and the outputs of each of the process steps proposed by Manson (2006).

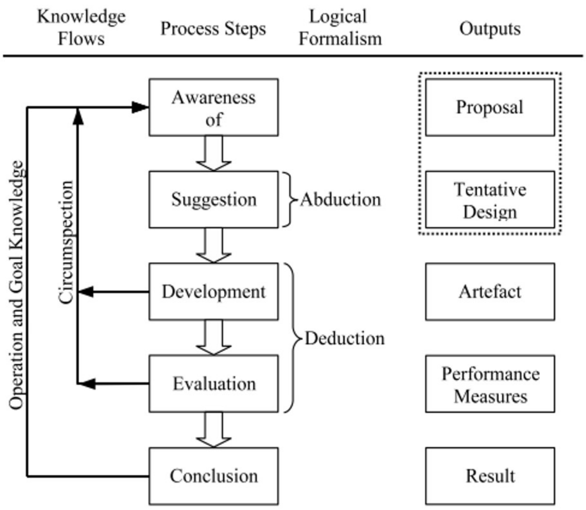

Figure 1. Framework that guides this research. Manson (2006).

The method adopted followed the steps shown in Figure 1. The "Awareness of the problem" step included an analysis of the auto parts industries' scenario. The constant demand for productivity has been a way of achieving competitiveness in this market, and a means for this are the production systems consolidated worldwide. In line with the need for continuous improvement, Industry 4.0 helps enhance the practices addressed in these production systems, enabling technologies to develop a smart factory. Also, considering local factors, such technologies may have particularities regarding implementation.

In the "Suggestion" stage, the bibliography is reviewed for theoretical support in constructing the design of the proposed artifact to solve the problem in question. The search for articles was performed in the Scopus, Science Direct, Emerald, Springer, Elsevier, and Scielo databases and searches through Google Scholar, including specific conference proceedings. The keywords searched were: Production System, Lean Manufacturing, Lean Production, Production, Discrete Event Simulation, Production Strategy, Auto Parts, Virtual Factory, Manufacturing Strategy, XPS, Toyota Production System, Hyundai Production System, Volvo Production System, Industry 4.0, Advanced Manufacturing, "Lean" AND "Industry 4.0", "Lean" AND "Advanced Manufacturing", "Hyundai" AND "Industry 4.0", "Hyundai" AND "Advanced Manufacturing", and variants. The results made it possible to build the artifact's design to develop a Production System specific for the auto parts industry, including elements from Industry 4.0 and considering the best practices of previous systems already consolidated.

In the "Development" stage, the conceptual model is proposed, used as the basis for constructing the artifact – for now, called Production System 4.0 for the auto parts industry. The steps used in the construction of the artifact were: (i) propositions of the authors of the research; (ii) construction of the conceptual model for the 4.0 Production System for the Auto Parts Industry; (iii) artifact proposition; (iv) practical application of the artifact; and, (v) evaluation of the process and its results (the next step).

The "Evaluation" stage consists of the practical application of the artifact in an auto parts industry located in southern Brazil for evaluation and, if necessary, the adaptation of the model. This evaluation aimed to improve the Production System 4.0 for future validation. In the evaluation, the following criteria were observed: (i) lead time (hours); (ii) hour man/fuel tank produced (HM/Fuel Tank); (iii) Work In Process (WIP) (number of tanks); (iv) total distance traveled by operators; (v) economic gains through Return on Investment (ROI).

The multi-criteria Technique for Order of Preference by Similarity to Ideal Solution – TOPSIS was chosen to connect all the criteria evaluated. TOPSIS is among the most widespread multi-criteria ranking methods (Silva & Almeida Filho, 2020). The technique demands the attribution of evaluation marks for all alternatives against all evaluation criteria as input data. The output generated by the method is simple to interpret, as it is a coefficient, in which the option with the highest coefficient is the alternative closest to the ideal solution and, at the same time, the most distant from the anti-ideal solution, being considered the best compromise solution (Jahanshahloo et al., 2009; Silva & Almeida Filho, 2020).

Finally, the research results are presented in the "Conclusion" stage and a rigorous analysis of its academic and business contributions. There were also possible deviations from what was planned and lessons learned during the process. Opportunities observed throughout the research that this article could not address were also explained here. The artifact implementation was not performed in this article because after obtaining the best simulation scenarios, these were used to manufacture the artifact. Thus, its physical implementation does not fit at this time because the best implementation strategy and cultural adaptation necessary for companies that adopt this artifact are subsequently proposed.

Table 2 summarizes the DSR steps and their outputs described exclusively for this research. The deliverables (results) are associated with the corresponding specific objectives that lead to the achievement of the study aim. The structure followed was suggested by the authors Manson (2006) and Goecks et al. (2021).

Table 2. Working method from the DSR.

Process Steps	Outputs
Awareness of the problem	Design a production system considering the practices of previous methods and systems that allow designing Industry 4.0, showing a path for companies to evolve towards Industry 4.0;
Suggestion	Analysis of the available literature to build the Artifact design to propose a method for implementing a Production System for the auto parts industry with elements from Industry 4.0 and with the best practices of production systems;
Development	Construction of the proposal of the conceptual model and the artifact now called method for implementing a production system for the auto parts industry;
Evaluation	Practical application of the proposed artifact and evaluation of the process and its results;
Conclusion	Presentation of the proposed artifact for analysis regarding the research objective.

4. Results

4.1. Conceptual model

After a critical analysis of the literature, it became possible to draw up a conceptual map referring to the constructs and interactions of the Hyundai, Volvo, Ford, Toyota, and related Systems and the technologies that make Industry 4.0 viable. This conceptual map (Figure 2) synthesizes and highlights the main elements of the theoretical framework that guides this research.

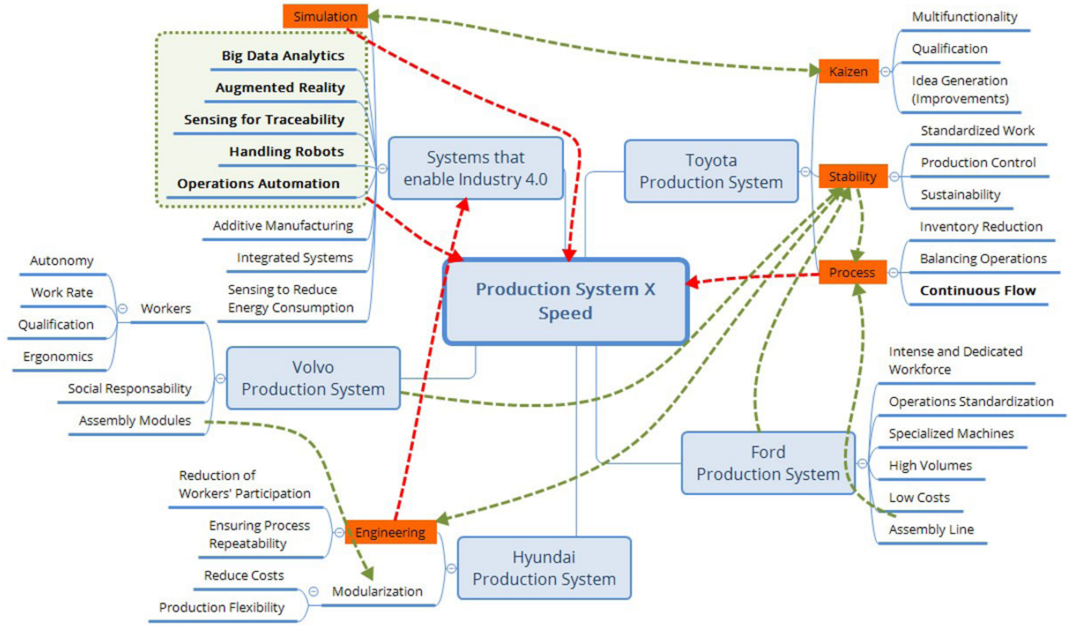

Figure 2. Conceptual map of the production systems.

The conceptual map highlights the constructs that make up the proposed production systems, the relationships, base, and central pillars (underlined in orange). The reading of the concept map begins with "Stability", an integral concept of TPS, which has a strong relationship with the Mass Production Systems and VPS. The structured process makes it possible to assess improvements through the constructs "Process" and "Engineering". For "Process", regarding the reduction of inventories, leveling operations, and continuous flow. For "Engineering", an opportunity to advance technologically with elements of Industry 4.0 and guarantee the repeatability of the process. Industry 4.0 complements this map with technological inclusion as they become more financially attractive. The green lines show the relationship between the constructs, and the red strings show the relationships between the constructs and the proposed conceptual model. Concepts from HPS, TPS, and others, together with Industry 4.0 technologies, enable a faster process (center of the concept map).

Coming from TPS, "Stability" is responsible for developing competencies, standardized operations, and sustainability. Production stability helps to reduce waste as possible without affecting safety and guaranteeing product quality. Resource planning must be carried out carefully to avoid wasting as much as possible or not providing the necessary resources to meet the demand. In particular, 4M (Method, Machine, Man, and Material) must be planned. Stabilizing processes drives improvements in deliveries, minimizes rework costs, maximizes resources, and ensures a more robust system. This also implies continuous monitoring and control of the root causes of instability. Production monitoring is suggested to identify deviations between actual and planned (Dennis, 2017). It is possible to develop the pillars from this base: "Process" and "Engineering".

The "Process" pillar (leveling and production flow) is developed by the need to reduce inventories and balance operations, directing efforts to verticalize the factory in a continuous flow. Therefore, it can be said that the constant flow is extracted from the concept of the moving assembly line proposed by Ford, which aims to eliminate production stops and restarts, reducing lead time and non-processing time. However, the idea of reducing the in-process inventory is maintained, being obtained from stable processes (Dennis, 2017). Next, the "Engineering" (technologic innovation) pillar evaluates and eliminates possible errors and human failures in manufacturing operations, combining HPS with elements from Industry 4.0 in a more technological look, that is, improving lean manufacturing concepts with technologies associates (Scheer, 2015). Also, at the top of the custom production system (XPS), the concepts "Speed" (shorter lead time) and "Operational Result" are presented.

One of the indicators of organizational effectiveness is "Speed", through a shorter time for full service to the end customer. The lead time of the proposed production system artifact includes the processing time of the products and other stages of the production process (Dennis, 2017). This is considered one of the main XPS outputs, measured before and after the simulation. Also, the "Operational Result" of productive activities can contribute to the improvement of operating profit, contributing directly or indirectly to the sale price. In XPS, the operating result is presented by indicators.

Finally, the XPS system should aim at "Continuous Improvement" (structured from Kaizen), transforming the learning from training into practical results. The Kaizen philosophy seeks to develop a culture of problem-solving to improve processes, eliminate waste, and involve people to maintain long-term effects (Berger, 1997), contributing to increased productivity (Berger, 1997). To guarantee the maintenance of XPS, the process's stability and the organizational culture are necessary for the search for continuous improvement.

4.2. Artifact development

The development of the artifact was structured in four phases, with the completion of one step not being necessary to advance to the other. In addition to the objectives mentioned above, the artifact is developed to disseminate and sustain the continuous improvement culture through people qualification and development. The team involved participates in qualification workshops and, mainly, in practical activities at Genba. The unfolding of the phases is explored in Figure 3.

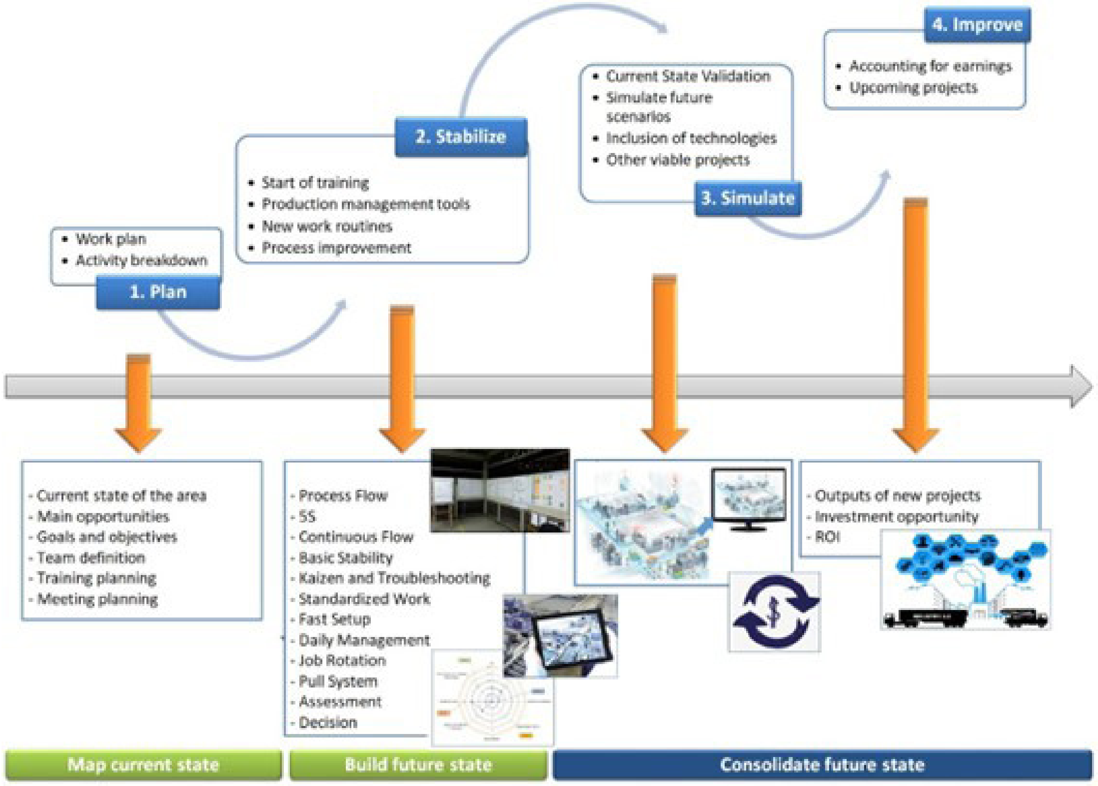

Figure 3. Proposed Method for Implementing the Production System for the Auto Parts Industry (XPS).

4.2.1. Phase 1: Plan

A general evaluation of the current status of the area chosen for the project is conducted, verifying the main results. Thus, a multidisciplinary work team was structured for the project's development, composed of representatives from influential departments in the development process and by the area's leadership. The selected participants must have the ability to multiply the knowledge acquired to support the new principle, method, and technique in their departments, also helping to spread the culture of continuous improvement in the company. For better project organization, a work plan is prepared, which must contain:

- Objectives and goals: expected results at the end of the project;
- Participating team: definition and assignment of responsibilities;
- Training planning: qualification of the multidisciplinary team;
- Planning of meetings: discuss and monitor the evolution of actions and keep stakeholders informed of the project's progress.

Still, suppliers can also be considered because a specific team can be structured to improve the inputs provided. Thus following the exact structure of the work plan.

4.2.2. Phase 2: Stabilize

After planning, the team qualification and improvement implementation are started according to the area's priorities. The choice of training to be given considers the particularities of the sector and its objectives. The training is carried out by a specialist in the area, who is also responsible for coordinating practical activities (carried out in Genba). Table 3 shows the dynamics of this process, that is, the expected outputs of each training.

Table 3. Outputs Practices Training.

Training	Output from each training
1. Introduction to lean mindset	Initial training where the solution is to strengthen the team to pursue the project's objectives.
2. Production System Academy	Hands-on training in a laboratory where the output is to build miniature tractors, make four production runs, and advance in each one with production management tools.
3. ValueStreamMapping	Know the process flow, identify opportunities for improvement and project a new future state, which will be targeted by the project team (which may be in conjunction with the simulation).
4. A3 Management	Project contract, contemplating the objectives and goals that the team will pursue
5. Workplace organization	Implementation of organization and cleaning routines in the area and standardization.
6. Daily Management	Aid chain implementation, production analysis framework (planned vs. realized), Andon and Kamishibai.
7. Quick tool change	Mapping internal and external setup by machine, in-sight Management of instruction, and monitoring tool change time.
8. Kaizen and Troubleshooting	Problem-solving method, Ishikawa, five whys (practiced in Genba).
9. Multifunctionality	Construction of the staffing table and versatility matrix, implementation of job rotation, and spot management to monitor qualifications.
10. Stabilizing production	Table of production capacity per machine, Pareto chart of problems per machine, raw material supply routines.
11. Continuous flow and standardized work	Review daily management training outputs, evaluation of new layout opportunities, and construction/improvement of standardized work instructions.
12. Pull system and production leveling	Kanban implementation.

The first challenge of this stage is the selection of tools and training that contribute to the productive flow of the area in question and align all members with the defined objectives. This phase is responsible for the project start meeting. The A3 is presented to all company leaders, always after the training, to commit with those involved in the search for results and reinforce the importance of the project. As a symbolic form of commitment to the project, all participants sign the A3. The company president welcomes and closes the meeting at this event, reinforcing the business strategies for the project in question. In this way, the project results are monitored monthly through indicators and evaluated in the Assessment stage.

Assessment is used to audit the XPS implementation, assessing what is in compliance and what needs to be corrected, and is conducted by a trained company team. It is based on a checklist to detect errors and potential failures, composed of thirteen questions that receive grades from zero to ten (0 = the needs were not met; 10 = the needs have been met completely). With the XPS audited, an action plan is drawn up to help prioritize the actions to better use resources. Figure 4 shows the eight pillars of Assessment, two in the management scope, three in the Process Function, and two in the Operation Function.

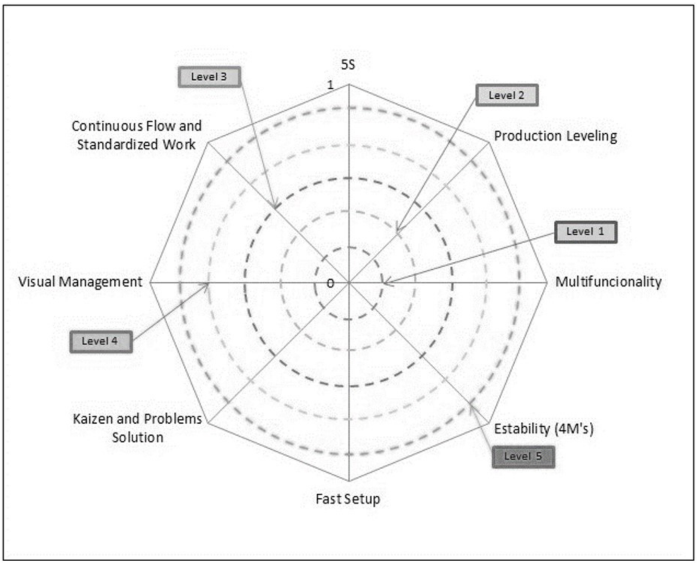

Figure 4. Assessment application on the production line.

It is observed that the assessment presented in Figure 4 is structured from the Lean tools, which serve as a basis for Industry 4.0. Research suggests that digital transformation becomes more viable from a well-founded Lean framework (Bittencourt et al., 2020). Furthermore, the use of Industry 4.0 Technologies also contributes to improving the maturity level of these tools (Lai et al., 2019). Thus, considering that the company's process already used some Lean concepts, the assessment points to be improved are necessary regarding the use of Industry 4.0 Technologies.

The organization of the workplace – 5S – (Management) aims to eliminate waste that does not affect product quality. The production leveling (Process Function) assesses whether the demands and deadlines are being met according to the planned schedule. Multifunctionality (Operation Function) verifies whether the tools for people management ensure the stability of the workforce and whether practices are being carried out to improve people management indicators. Stability (Process Function) is attentive to assessing whether leadership and supervision follow production data to ensure consistency and robust action. The fast setup (Operation Function) measures whether the implemented methodology guarantees adequate availability for production. The Kaizen and Problems Solution (Management) verifies that anomalies are resolved and that the leadership and operational team follow the methods of problem-solving and continuous improvement. Visual Management assesses whether it is being applied to the Management and deployment of the company's strategy. Finally, the continuous flow and standardized work (Process Function) checks the use of "one peace flow" (reduction of lead time), scrapping costs (manufacturing large batches), whether there is standardized work (even if employees are performing), and whether the targets are being met. These eight pillars generate a grade, which may have the following classification, as shown in Table 4.

Table 4. Assessment classification and outputs.

Classification	Performance	Description
Gold	91% to 100%	Excellence–acting sustainably*
Silver	81% to 90%	Requires low complexity improvements**
Bronze	70% to 80%	Stabilized but unsustainable processes*
Back-to-basics	0% to 69%	Not able to move forward, needs to go back to bases and stabilize the operation

*Tools implemented and self-managed by the leadership; **Strengthen training and monitoring of employees.

After performing the Assessment and identifying opportunities for improvement, action plans are started to eliminate the problems found, regardless of the grade obtained. If the evaluation performance exceeds 69%, the project moves to the next phase. Suppose the performance is equal to or below 69%. In that case, the project must be postponed for the period necessary to resume the actions rated lower than expected in the evaluation and communicated to the sponsor.

4.2.3. Phase 3: Simulate

From the previous phases, it is possible to start the simulation process, which is subdivided into three blocks (pre-simulation, simulation, and post-simulation) – Figure 5; improving the understanding of the artifact. Several future scenarios are simulated, validating those that should be focused on. The proposed artifact consists of the union of the previously planned activities (described so far) and the steps necessary to build the computational model.

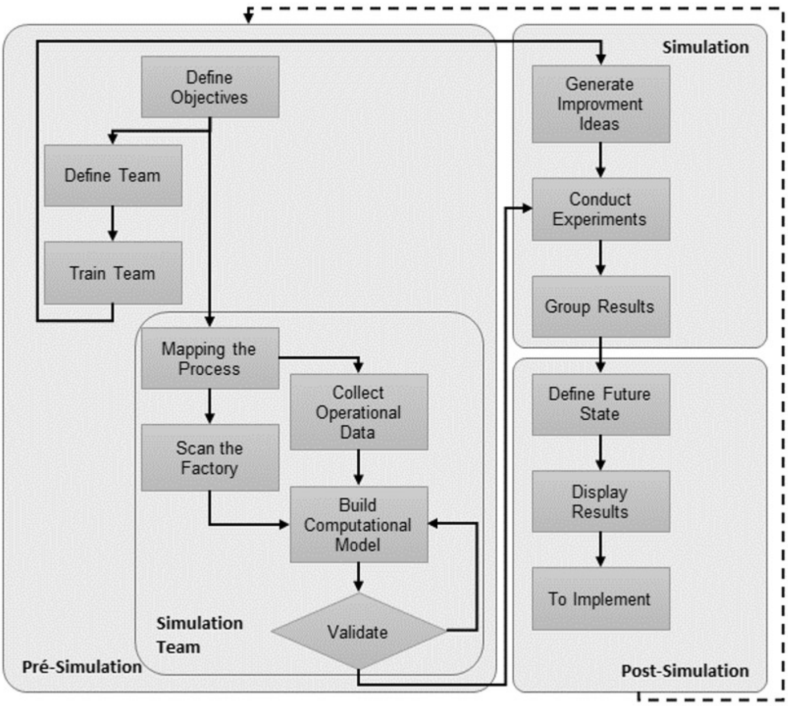

Figure 5. Simulation steps.

In the pre-simulation, data collection is carried out to provide structure for the development of the study, consequently improving knowledge about the analyzed area. Still, in this block, activities of the definition of objectives and team training, process mapping, the definition of operational data that feed the computational model, and validation are concentrated. In the next block, simulation, the improvement proposals are grouped; subsequently, future scenarios are generated by the modeling analyst, which is later compiled and analyzed to identify strengths that emerged from the proposition. Finally, in the post-simulation, the final analysis of the improvements, observing points of success and failures in the process, is carried out. In this block, the future state chosen in the previous evaluation must be defined and implemented, considering the conditions of the implementation plan and available investment.

4.2.4. Phase 4: Improve

It is the consolidation of work to recover the history of the activities carried out. Thus, creating a moment of closing this cycle and projecting the next future state. In this phase, the accounting of the gains obtained during the project and the lessons learned for the artifact's continuous improvement stand out; therefore, ROI is used for valuation and measured by the ratio between the result generated by assets and the number of investments made. Equation 1 demonstrates the calculation of ROI.

$$ROI = \frac{\left(return - \left(investiment \times anual\, taxes\, rate\right)\right)}{investiment} \quad (1)$$

It is observed that the improvement process meets the evaluation logic proposed by the DSR method, culminating in an improvement on top of what was proposed. The evaluation of financial gains is carried out through productivity gains and the reduction of intermediate stocks, as shown in Table 5.

Table 5. Transformation of performance indicators into money.

Indicator	Calculate monthly gain	Annual gain
Lead time	It is the main indicator, considering the reduction in operating times, reduction in setup times, exclusion of operations from the process, and reduction in work center costs. It is calculated by the unit cost of the improvement multiplied by the monthly demand.	Unit improvement gain multiplied by 12-month demand.
WIP	Reduction in the number of intermediate stocks. It is calculated by comparing the initial quantity with the final amount of the project.	Earning value (initial x final) multiplied by 12 months.
TD	Layout improvements. Calculated per reduced m^2.	Reduced m^2 multiplied by 1,000*
HM/Fuel Tank	Effort/outcome-related gains. Calculated by the implemented improvements multiplied by the number of employees at the project beginning, which is multiplied by 3,000*	Monthly gain value multiplied by 12 months

*Benchmarks.

4.3. Artifact validation in an auto parts factory

This validation aims to verify if the artifact, once put into practice, can answer the research question, showing its results through a critical evaluation. Currently, the company under analysis produces shaped metallic parts through cold processes (room temperature), called metallic stamping. Among the various products manufactured by the company, the aluminum fuel tank stands out, accounting for 15% of the company's revenue. This area was selected due to the need for a production capacity increase for this product, contributing to its competitiveness in the national and international market. The production line under analysis has several manufacturing cells. It was found that the layout of workstations can be improved, reducing the distance traveled between departments, consequently reducing lead time. This phase was structured in the following stages: identification of opportunities, team structuring, and follow-up meetings. The details of the steps are shown in Table 6.

Taking into account the opportunities mentioned, training was selected to qualify the project team, such as (i) introduction to lean thinking; (ii) value stream mapping; (iii) A3 Management; (iv) Daily Management; (v) quick tool change; (vi) Kaizen and troubleshooting; (vii) continuous flow and standardized work. After the training execution, the project's progress was evaluated through the Assessment and if the actions are taken so far were carried out correctly. Figure 6 shows the results obtained, with an average performance of 63% and positive highlights for fast setup, 5S, continuous flow, and standardized work.

In the search for stabilization, new training were carried out, including support materials for workers. After six months, in the second Assessment application, an average performance of 77% improved all elements, including the Kaizen and problems solution. With the advancement in team performance, the simulation phase (Figure 7) was applied to increase the artifact's effectiveness in assessing the future state through multicriteria decision-making and algorithms to simulate scenarios.

Following Figure 7, we proposed future scenarios simulated for the production process. Each scenario presented was planned by the project team and considered aspects of balance between investments and results obtained. In this sense, twelve layout proposals were generated (based on the assumption of Production System 4.0), which were then evaluated against the current scenario. At the end of the simulations, the results obtained and the ranking coefficients for the TOPSIS decision-making method were presented in Table 7.

It was disregarded in the multicriteria evaluation regarding the current scenario due to its obsolescence. Thus, scenario 12 obtained the best performance, followed by scenarios 09, 11, and 10. This ranking was already expected, as each new scenario construction considered the learning of the previous scenarios.

Finally, in the "Improve" step, the financial feasibility of the chosen scenario was evaluated based on the ROI. As for scenario 12, the investment value was estimated at R$ 1,452,351.00 with an estimated implementation time of four months. The return, also estimated, is R$ 45,104.00 per month, obtained through a 23% gain in lead time, 55% in WIP, 38% reduction in the distance traveled by operators, and 16% in HM/Fuel Tank, compared with the current operating state of the production line. With these data, an ROI of 9.22% was obtained for Scenario 12.

Table 6. Practical application of the artifact in an auto parts factory.

	Phase	Objective	Steps	Description
1	Opportunity identification	Convert an existing factory into a factory of the future (Industry 4.0)	Manufacturing layout	The manufacturing system layout must be evaluated and reorganized.
			Transport standardization	Use of automated transport technologies (AGVs).
			Reduce/Eliminate setup time	Improvements in the fixing structure and transport in the robotic welding station.
			Tank traceability	Track product movement at the factory and calculate the lead time (RFID, QR Code, or TaggenBeacon).
			Inventory reduction	Work on approaching the machines and directing the tanks to continuous flow (layout improvement).
			Integrate maintenance	Inclusion of technologies for monitoring equipment to predict preventive/predictive maintenance.
			Even and balance	Planning training for the team for a continuous flow and standardized work.
			Automate manual processes	Collaborative robots to assist in finishing routines, sharing the exact location with operators.
			Prediction technologies	A computational system for planning and dynamic production optimization (Big Data and Analytics).
2	Team structuring and meetings	Professionals who make a difference to the project and also be the change agent in their area of origin	Bi-monthly meetings	The sponsor, project manager, and Lean specialist present the indicators to the company's board and president.
			Monthly Meetings	The project manager and Lean specialist prepare a summary presentation of the project status and take it for the approval of all managers on investment needs.
			Fortnightly Meetings	The project manager, Lean specialist, and group coordinators come together to check the progress of the work and define the strategies for conducting the project.
			Weekly meetings	Group coordinators meet with their teams to conduct actions and update project pending issues.
			Daily Meetings	Follow what was planned by the production coordinators at the beginning and end of the work shift.

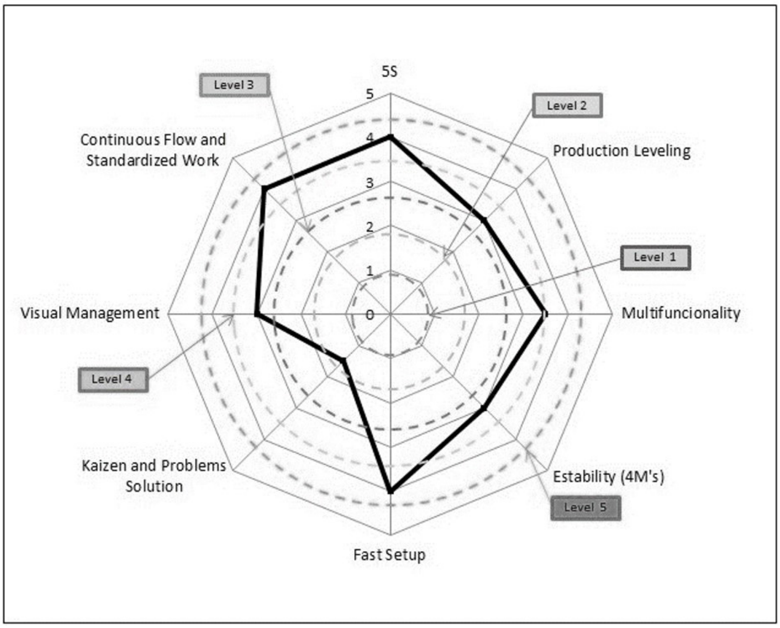

Figure 6. Assessment application on the production line.

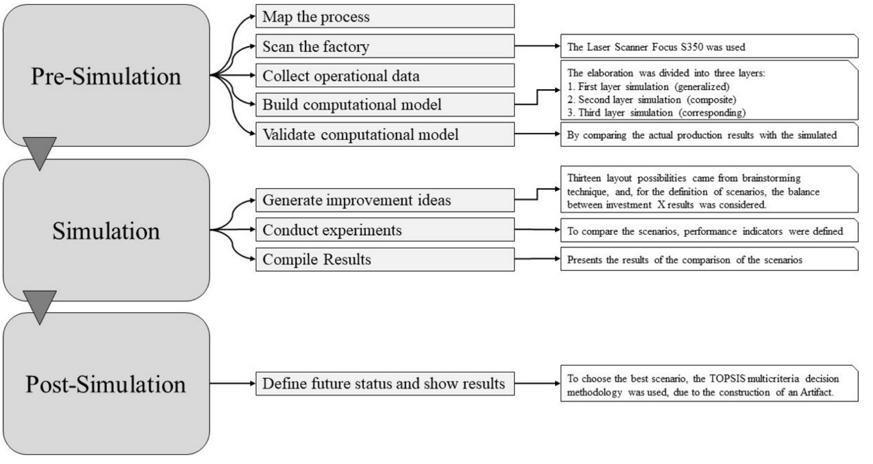

Figure 7. Simulation phase steps.

Table 7. Performance indicators, evaluation, and ranking of simulated scenarios.

Scenario	LEAD	WIP	TD	PRO	SETUP	HM	TOPSIS factor	Ranking
Current	6.0	50	329	988	74.5	3.3	--	--
1	5.9	132	454	1087	60.4	4.3	0.109	12
2	6.2	47	293	988	72.2	3.3	0.723	11
3	5.9	47	289	961	74.4	3.4	0.729	10
4	6.1	47	270	967	70.9	3.3	0.736	9
5	5.6	44	254	990	71.4	3.2	0.791	7
6	5.2	45	244	1022	68.5	3.1	0.823	6
7	6.1	41	331	1121	58.6	3.3	0.745	8
8	5.5	39	239	940	68.,4	2.9	0.833	5
9	5.4	34	235	999	51.9	2.8	0.902	2
10	5.4	38	232	939	70.4	2.6	0.840	4
11	5.5	32	208	938	69.7	2.8	0.853	3
12	4.9	36	216	977	51.8	2.6	0.931	1

Indicators	Description	Weight
Lead Time (LEAD)	= sum of operation times + sum of waiting times	30%
Work in Process (WIP)	= raw material used - units produced	15%
Traveled Distance (TD)	= sum of the distances covered by the operators	15%
Production (PRO)	= number of fuel tanks produced	15%
Total Setup (SETUP)	= sum of setup times performed	15%
Hour man per fuel tank produced (HM/Fuel Tank)	= Hour man / fuel tank produced	10%

Looking at the other scenarios, Scenario 6 draws attention due to its low initial investment and significant return. With an approximate investment of R$251,000.00, with two months to implement and an estimated operation return of R$8,098.00 per month. They are obtaining an ROI of 14.05%, better positioned than Scenario 12 in the ROI aspect. In addition, getting gains of 18% in lead time, 19% in WIP, and 30% in the distance traveled (compared to the current scenario). Both proposals showed significant gains to the operation, but the choice for scenario 12 obtains more excellent benefits than Scenario 6 but requires more substantial investment. The organization's strategy should consider, in decision making, how much money it has available for investment and the time needed for implementation.

4.4. Results evaluation

Following the steps proposed by Manson (2006) and Goecks et al. (2021), after the development stage, the evaluation of the artifact must be carried out. The points highlighted in the application of the method are presented below:

- The conceptual model of the proposed production system contributed to the creation of a new production system called XPS. It can be "named" Production System X (where X represents the name of the company), corroborating Netland (2013) and Netland & Sanchez (2014);
- The artifact fills a relevant gap in the company under study, providing a structured process to evolve towards Industry 4.0, reinforced by Esmaeilian et al. (2016). Contributing to a 4.0 Production System, emphasized by Sanders et al. (2016);
- The involvement of company professionals in the application and development of the artifact contributed to confirming the applicability of this method in the business environment, in line with the authors Stälberg & Fundin (2016). Favoring the stability of the process as a whole;
- The artifact proved to be a potential for the company's competitiveness, allowing for a strategic alignment about investments.

According to the results presented in this synthesis, using traditional tools in production systems and enabling technologies for Industry 4.0 tend to enhance the organization's financial and economic gains. Thus, the following results were observed:

- Lead time (hours): 23% gain for Scenario 12 and 18% for Scenario 6 (target above 20%);
- Hours Man/Fuel Tank produced: 16% gain for Scenario 12 (target above 10%);
- Work In Process (WIP) (number of tanks): 55% gain for Scenario 12 and 19% for Scenario 6 (target above 20%);
- Total distance traveled by operators (km/shift): 38% gain for Scenario 12 and 30% for Scenario 6 (target above 20%);
- Return on Investment: 9.22% for Scenario 12 and 14.05% for Scenario 6 (target above 5%).

According to the DSR research method, the evaluation of the results was carried out according to the seven requirements of Hevner & Chatterjee (2010):

- Artifact: it was built and applied, following the phases proposed by the work method to achieve the results;
- Relevance of the problem: the steps that companies must take to evolve towards Industry 4.0 to obtain improvements in their production process, according to the problem detailed in section 1 (Introduction), in addition to comparing the situation with section 2 (Theoretical Framework);
- Performance of the artifact: the implementation of actions, verification of the evolution of the indicators, and, above all, the final cost-benefit ratio of the project point to the effectiveness of the artifact's performance;
- Research contribution: the construction of the artifact presents an effective way to obtain improvements in production processes;
- The rigor of research: due to quantitative and practical evaluation;
- Research process: the study followed the steps proposed in the literature. Contributing to the debate on the practical application of new concepts in the application of the elements of Industry 4.0 in Auto Parts Industries;
- Research communication: from the unfolding in scientific articles and contribute to future research.

This research is considered relevant insofar as it sought to discuss practical and recurrent issues in the business environment, using the scientific process of knowledge construction to solve a functional problem and advance theory. The research process was conducted following the general steps of the DSR, expanding the debate on emerging methods of knowledge construction in the field of engineering. The research was conducted with methodological rigor, and the results are communicated through this study.

5. Final considerations

This research proposed implementing a Production System for the Auto Parts Industry with elements from Industry 4.0, developed from the DSR. The literature identified the central production systems in Mass, TPS, VPS, and HPS, including the practices that allow designing Industry 4.0 in a new production system, improving existing concepts. From the characterization of Industry 4.0 and its association with the best practices of production systems, it was possible to define the constructs for the elaboration of the XPS conceptual model, showing the opportunities for gains and time reduction.

To summarize the analyzes carried out, it is highlighted that the proposed method contributes to a competitive differential for the company, given the results obtained of 23% in lead time, 16% in HM/Fuel Tank, 55% in WIP, 38% in total distance traveled by operators, in addition to an ROI of 9.22%. With the gradual reduction in the costs of Industry 4.0 technologies, the gains will tend to be greater, affecting the company's competitiveness and productivity. In general, it can be concluded that the artifact contributed to the expansion of knowledge of the participants involved and reinforced their interest in monitoring performance indicators and managing the results obtained in this industrial sector.

The practical application of the artifact showed that its use is possible; however, to extract the maximum potential, it must be inserted into the company's culture. However, the enhancement of this artifact can be done with other technologies from Industry 4.0, such as Big Data, the Internet of Things, among others. Still, the conceptual model can be expanded according to the World Class Manufacturing methodology developed by Fiat and its partners. The production mix must be evaluated regarding the simulation, which may consider market fluctuations.

The inexistence of a budget forecast for immediate application can also be considered a work limitation. In addition to this, the financial results were little explored. The need for a long-term follow-up becomes a practical limitation of this study. Consequently, when viewed over a more extended period, it can be evaluated in practice regarding the impacts generated in the chain.

Finally, due to the nature of DSR, the generalization of this method can be better studied in other business environments, considering that the artifact was applied in a specific case. However, it is possible to use it as a basis for adaptations to different contexts, and consequently, it can be adapted and expanded to the automotive chain.

As for future research, in addition to the limitations mentioned earlier that can be improved, this study can be extended to suppliers and customers. Thus, the artifact can be evaluated by other financial analysis tools and delving into the economic aspect, including assessing how each element of the production system impacts each competitive criterion (performance indicators). Finally, it is highlighted that the inclusion of Industry 4.0 in the production environment is considered one of the trends for the industry's future. Given this, organizations prepared for change, building the necessary organizational capabilities, will have a competitive advantage and benefit from these technologies.

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