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The Journey from Lean Manufacturing to Industry 4.0: The Rail Manufacturing Process in Mexico

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Abstract**—**Nowadays, Lean Manufacturing and Industry 4.0 are very important in every country. One of the main benefits is continued market presence. It has been identified that there is a need to change existing educational programs, as well as update the knowledge and skills of existing employees. It should be borne in mind that behind each technological improvement, there is a human being. Human talent cannot be neglected. The main objectives of this article are to review the link between Lean Manufacturing, the incorporation of Industry 4.0 and the steps to follow to implement it; analyze the current situation and study the implications and benefits of this new trend, with a particular focus on Mexico. Lean Manufacturing and Industry 4.0 implementation waves must always take care of the most important capital – intellectual capital. The methodology used in this article comprised the following steps: reviewing the reality of the fourth industrial revolution, reviewing employees' skills on the journey to become world-class, and analyzing the situation in Mexico. Lean Manufacturing and Industry 4.0 were studied not as exclusive concepts, but as complementary ones. The methodological framework used is focused on motivating companies' collaborators to guarantee common results, innovate, and remain in the market in the face of new requirements from company stakeholders. The key findings were that both trends emphasize the need to improve communication across the entire company and incorporate new technologies into everyday work, from the shop floor to administrative staff, to help improve processes. Taking care of people, activities and processes will bring a company success. In the specific case of Mexico, companies in all sectors need to be aware of and implement technological improvements according to their specific needs. Low-cost labor represents one of the most typical barriers. In conclusion, companies must build a roadmap according to their strategy and needs to achieve their short, medium- and long-term goals.

Keywords**—**Lean management, lean manufacturing, industry 4.0, motivation, SWOT analysis, Hoshin Kanri.

I. Introduction

LEAN management systems have opened up a new way to manage companies since their introduction in 1960. One example is the Toyota Production System, which aims to eliminate waste, emphasizes the enhancement of shareholder value, and uses value-based management [1]. Nowadays, a new variable has come into the equation for companies to survive and be successful in an increasingly digital market: the so-called Industry 4.0 (I4.0). This new era was declared at the Hannover Messe trade show in 2011 [2]. In this exploratory work, we look at the convergence of Lean Manufacturing (LM), lean management, and I4.0. Our aim was to understand and integrate the principles of LM, lean management and I4.0 with the importance of including human and intellectual capital. Human beings and their needs must be considered when incorporating I4.0 and LM. The technical literature was searched using Google Scholar.

The main objective of this article was to integrate the steps to follow to incorporate both methodologies, and determine the current state of play, as well as the resulting challenges and benefits.

Specific objectives:

- Compiling the theoretical framework.
- Identifying the steps to follow and to consider before implementing LM and I4.0.
- Summarizing the main challenges that apply to Mexico and interpreting the benefits of applying LM and I4.0.

II. Theoretical Framework

A. LM Methodology: Lean Thinking & Lean Management Trends

LM focuses on eliminating the seven wastes (muda) and producing profit by eliminating costs (Fig. 1) [3]. According to Mrugalska and Wyrwicka, there is a "lean toolbox", and every company needs to decide which tools to put into it [4]. The Toyota model distinguishes between two pillars: just-in-time (focusing on the client), and jidoka, which is about building quality in the product and making anomalies in the process visible. At the center of the model are employees and teamwork, with enterprise objectives and key performance indicators (KPIs) at the top [5].

It has been proven that lean thinking is a powerful philosophy to optimize operations throughout an entire manufacturing company. This philosophy is driven by customer demand and by applying the principles of value creation, waste elimination, respect for people, and continuous improvement [6].

The characteristics of a lean organization focused on lean management include teamwork, involving everyone from the operators to the administrative staff; active shop-floor problem solving structures, Kaizen activities, low inventories, prevention rather than correction, just-in-time production, and cross-functional development teams [4].

Solaimani et al. propose a way of conducting leadership coaching through lean management, combining, in a very successful way, the purpose of lean methodology: the perspective of added value, combining with the achievement

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of goals and work motivation [7].

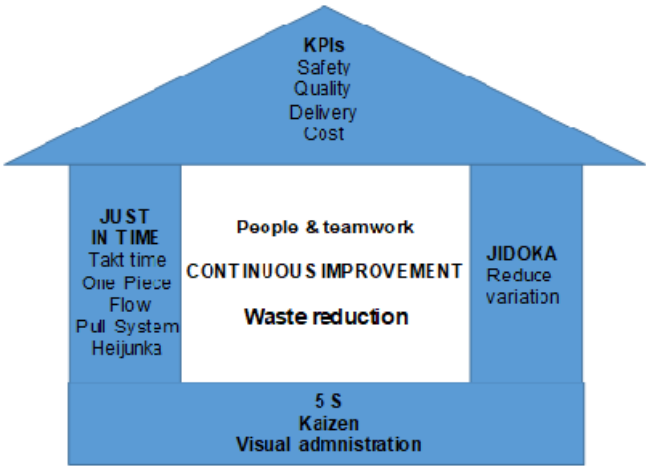

Fig. 1 Adaptation of Toyota Production System [3]

B. Industry 4.0

The first three industrial revolutions took place almost 200 years ago [2]. I4.0 enables real-time communication, data storage and data analysis to take place faster than in the previous three. I4.0 aims to generate connection and communication through the internet of things (IoT), the transformation or conversion of data (use of big data), storage capability (Cloud), and learning through data (artificial intelligence) [8]. It represents the increasing usage of the latest technological advancements in IT and communications to enable human beings, machines, products, and resources to exchange information with each other [3].

The first part of I4.0 is data acquisition and data processing. Recently, sensors and actuators, cloud computing, big data and data analytics have been used to achieve this. The next step is machine-to-machine communication (M2M), which involves both vertical and horizontal integration and human-machine interaction (HMI), such as virtual reality and augmented reality [3].

C. LM and I4.0: Some Links

Literature and studies have been made to compare LM and I4.0 tools (big data, cloud computing, etc.). The application of I4.0 can stabilize and support the principles of LM. Wagner [3] designed a table (Fig. 2) as a frame of reference to begin the integration of I4.0. The left-hand column shows the most common LM tools and the top row shows the most common I4.0 tools. The number of asterisks denotes how well the tools complement each other [3].

Both approaches share common principles, however, they have different strategies. One of the principles of LM is stability in production levels and decreasing variability, while I4.0 encourages and facilitates management of production levels and production variability. LM is a necessary foundation for I4.0, including full employee involvement [5].

I4.0 applies advanced information and communication systems that are customer-value focused, one of the principal methods of LM [9].

	Data acquisition & processing	Machine to machine communication (M2M)	Human - Machine Interaction (HMI)
	Sensors, cloud computing, big data, analytics	Vertical and horizontal integration	Virtual & augmented reality
5S	*	*	**
Kaizen	**	***	***
JIT	**	***	**
Jidoka	***	**	*
Heijunka	***	**	*
Standardization	**	*	***
Takt time	*	***	*
Pull flow	**	***	*
Man-machine separaton	*	*	***
People and teamwork	*	*	***
Waste reduction	*	***	*

Fig. 2 I4.0 and LM Matrix adaptation from Wagner [3]

One of the similarities between both strategies is the integration of the human factor. The commitment and integration of employees is required, through training, to show why the changes are needed within the company. The purpose of this integration is to obtain all the employees' experience and knowledge to make the implementation more effective. This perspective applies to any new strategy to be implemented.

Bongomin et al. emphasize that I4.0 is not just about introducing new technology and adapting work systems, as in the previous three industrial revolutions. I4.0 requires new technologies and forms of application involving different degrees of technical maturity and systemic effects [10].

D. Deployment of the Company Strategy: Hoshin Kanri

The idea of "strategy" dates to the military arts in ancient China, due to the similarity between markets and wars. Today, companies still seek to develop strategic models to achieve their objectives and goals. Professor Yoji Akao carried out work applied to the postwar Japanese economy, called Hoshin Kanri. Ho means method, hoshin means compass, and kanri means management [11].

A fundamental part of a good Hoshin Kanri is a SWOT (strengths, weaknesses, opportunities, threats) analysis. A SWOT analysis is useful in order to ascertain the current state of play and facilitates the diagnosis and evaluation of the strategy. The suggested steps are to define the mission and vision of the company, and then analyze the internal and external conditions. This analysis must be done at least in groups of 3-5 people. In conclusion: strengths + opportunities = optimization factor, weaknesses + threats = risk factor [12].

Kesterson proposes a 5-step model to implement Hoshin Kanri: "Scan" (the strategy formulation process), "Plan" (the Hoshin Kanri process begins), "Do", "Check", and "Adjust".

The "Scan" step uses a SWOT analysis and involves designing the desired future state to identify any gaps and prioritize them. It also involves doing a "catchball" process with team members, which is an interactive process of tossing items and possibilities back and forth. The "Plan" step is how the actions will be applied and measured. In the "Do" step, the plan is executed, and a bowling chart is implemented. Then, in the "Check" step, the results are reviewed and analyzed. Finally, in the "Adjust" step, countermeasures are implemented as needed. This 5-step model is shown in Fig. 3 [13].

Hoshin Kanri steps			
1	Scan	Strategy formulation plan	Mision-Vision statement, values, current state, desired future state, gap analysis, prioritize. *Catchball.*
			Objectives and measures - SMART -
2	Plan	Hoshin Kanri process begin	How will accomplish each objective.
3	Do	Execution of the plan.	Implementation of bowling chart.
4	Check	Review and analyze the results.	
5	Adjust	Document and standardize, or implement countermeasures.	Repeat the process 3 - 5

Fig. 3 Hoshin Kanri basic steps [13]

E. Implementation of I4.0: Defining the Current State

According to the literature, there are different ways to implement the concepts of I4.0. Several authors mention the use of roadmaps that set out the steps to follow in a structured way [14].

The main thing to do is to examine the maturity level of the company, determine where it currently stands and identify where it wants to go. Inków, citing Wendler, mentions the importance of using a maturity model which "defines a set of levels or stages […], these stages should be sequential in nature and progression, and should connect to organizational structures and activities" [15].

Pessl [16] developed a six-step roadmap approach, covering the areas of purchasing, production, intra-logistics, sales, and human resources. His software version of this proposal works with Microsoft Excel, which is an easily accessible tool. The first step is to analyze the current state, define the objectives, define the strategies, come up with specific objectives which will be measured in a balance scorecard, and define the target state, as well as the projects and scheduling. Pessl's [16] adaptation is shown in Fig. 4, where the suggested accountability step has also been added. On the other hand, as mentioned by Ghobakhloo [2], each company must determine its own roadmap, because each company has its own idiosyncrasies. Implementation must be based on the company's core competences, motivations, capabilities, goals, and budgets, and the cost-benefit ratio of the implementation must be analyzed. Road-mapping is a method that has become important to create and deliver strategy and innovation around the world [2].

1	2	3
Analysis	**4.0 Maturity test**	**Define target state**
Team Awareness	Procurement, Human, Production, Infralogistics, Sales.	Procurement, Human, Production, Infralogistics, Sales.
Accountability	**Define Projects**	**Define & evaluate measures**
Track results.	Sequence of projects.	Impact - Effort matrix.
6	5	4

Fig. 4 The 6 step roadmap for I4.0 implementation, adapted from [16]

F. I4.0 Implementation: Challenges to Consider

Internationally, some challenges have been detected when it comes to incorporating I4.0. These challenges include the strong pressure to increase the level of digitization, adapt production lines to new technologies, and redefine the role of people in those processes [16].

Other challenges to consider on a global level are the lack of knowledge about technologies and their opportunities, limited trained human resources, limited financial resources, planning and scheduling without milestones, prioritization in implementation, and limited investment [17]

Forbes [18] mentions that in Mexico, there has been very slow progress in the face of this fourth industrial revolution, which is attributed to the low cost of labor [8].

G. Benefits of Implementation: Why to Consider It Despite the Challenges

Some of the benefits that have been described are improving communication across teams and organizations, efficient time management and planning, guiding and leading the project teams, and visualizing goals, processes, and progress [17].

IoT, the cloud, big data and analytics are called "base technologies". Big data gathers information from systems and objects, such as sensors, with analytics. These technologies are considered an advantage for the future [19].

Real-time information, data storage, and data processing are important due to the decisions made and the changes made to add value to products and services, thereby meeting the needs of customers and stakeholders.

IoT is a technology that allows any physical object, with a network card, to be connected to any other object around it [8], increasing the scope for creativity in solving problems related to processes. As an example, the introduction of technology enabling flexible lines can automatically adjust production processes to multiple types of products and changing conditions [19].

H. Talent Development to Face the New Industrial Revolution

There are two groups of skills: technical (or hard skills), and personal skills (known as soft skills). Technical skills are subcategorized into theory and practice [10].

Some important soft skills are needed for strategic management and talent management practices to increase

productivity, efficiency, and competitive advantages [17].

To succeed, we need to combine process standardization with the people factor (with all that entails). When planning to incorporate new technologies, it is necessary to develop training programs for employees and recruit new talent if needed. In this regard, the projected top 10 required employee skills in 2020 [17] were:

- Complex problem-solving.
- Critical thinking.
- Creativity.
- People management.
- Coordinating with others.
- Emotional intelligence.
- Judgment and decision-making.
- Service orientation.
- Negotiation.
- Cognitive flexibility.

Sharing the "Why", or the company's strategy to implement and focus this new revolution, will make the transition easier. As shown in Simon Sinek's Golden Circle [20] (Fig. 5), the "Why" comes first, then the "How", and finally the "What".

Hypothetically, the changes brought about by I4.0 are easier for millennials to adopt, as they have grown up in an environment where data and people are highly accessible by digital means. This new generation is highly integrated with social media. As a result of this integration, there is a need to re-skill current employees through training programs, or even by re-designing work processes [17].

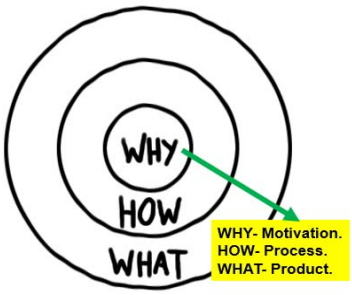

Fig. 5 Golden Circle [20]

Motivation and job happiness are an important part of the new revolution, to keep staff aligned with the "Why" of the company. In Mexico, employees spend one third of their day at work.

Motivation is valued as one of the most critical variables to improve productivity. To gain and sustain competitive advantages, all resources, including people, must be efficient and effective [21].

I. Improving the Current Education System to Ensure New Talent for I4.0

Karacay states that the adoption of I4.0 brings about the elimination of lower skilled jobs through automation and digitalization [22]. According to the same author, the new skills for 4.0 workers, as they are known, are:

- Having a good understanding of information transparency.
- Self-management and decision-making.
- Able to use digital communication.
- Being very flexible.

Engineering education programs should include big data, cloud computing, data analytics, artificial intelligence, IoT, and other similar technologies.

Bongomin et al. summarize the concepts of Education 4.0, Operator 4.0 and Learning Factory and propose the need to take these three concepts into account. Education 4.0 produces skills for I4.0, and combines technology with education, empowering companies to produce innovations and technologies according to society. The Learning Factory permits both technical and soft skills, with the aim being to incorporate laboratory and classroom. Operator 4.0 is referred to as the "operator of the future" and a "smart and skilled operator", performing "work aided by machines" if needed [10].

J. Industry in Mexico: Some Experiences

During the 18th and 19th centuries, with the introduction of the steam engine, factories faced the dilemma of whether to pay for machines or labor. This dilemma continues in the present day. For instance, in the state of Michoacán, there is an avocado packaging company that has computerized or automated most of its processes but is still manually selecting the product [18].

Other similar studies state that in the state of Nuevo León, Mexico, 46 education programs were changed to include topics such as digitalization. Since then, 500 engineers have been trained in those topics, according to the Vanguardia Industrial [8].

Mexico has a history of trying to gain global recognition as a leader in I4.0, along with other nations. At the 2018 Hannover Messe trade fair, Mexico secured 700 million dollars' worth of business, attracting foreign direct investment projects [23].

Since the fourth industrial revolution is so focused on innovation and scientific and technological development, there is a high risk of being left behind. Mexico must prepare and adapt to get ahead where possible and must accept the challenge [24].

In the railway sector, there are artisanal processes in most of its value chain, due to its nature. Added value is everything that the client is willing to pay for, that is done right the first time, and that transforms the product itself into a good or service.

Against that background, in the process of making a railway car, most of the value is added by hand, using the expertise of an operator.

The COVID-19 pandemic has resulted in the need to be connected remotely, which is forcing us to adapt faster to new technologies, particularly for communication purposes, adapting and incorporating them into our day-to-day work and investing in what may previously not have been a palpable need.

III. Methodological Framework

The technical literature was searched using terms including: "Lean Manufacturing principles", "Lean Management", "Smart Manufacturing", "Learning Factory", "Lean thinking", "Industry 4.0", "HoshinKanri", "Joy at work", and "Big data analytics". Next, we looked at similarities and correlations between LM and I4.0, Education in Mexico 4.0, Mexico and I4.0, and so on.

Currently, one railway company in Mexico is undergoing a process to implement lean methodology (considering the I4.0 profile). Unlike in the automotive industry, the lean methodology philosophy is not well integrated in the railway sector. This process began officially in 2013 as a pilot in one of the company's business units.

Seven years later, in 2020, a survey was conducted on a small group of employees from all departments and organizational levels of the company. Those surveyed were asked their age, educational level, whether they had ever been part of a strategy deployment, whether they were familiar with LM and if so, what tools, their knowledge of I4.0 and related tools, what motivated them, and whether they would like to participate in the deployment of the strategies.

IV. Results

By applying the basics of LM, considering the entire incorporation process, it was decided to compare and distinguish between the concepts applied at global level, lessons learned in relation to the nature of the railway segment, and the existing conditions in Mexico. A theoretical framework was put together, which must always be compared with the cost-benefit ratio of implementation. As mentioned before, one of the main challenges is the lack of formal education in the features of I4.0 under the current educational system, and existing employees who need to be trained in new technologies. These new tools should facilitate day-to-day activities and not result in extra work for employees.

It is not just in relation to robotics that I4.0 is mentioned; this is a common misconception. I4.0 involves data sources, data collection, data storage, data processing, results visualization, and data application [25]. Real-time information improves the results of processes, whether these are administrative or shopfloor.

Regarding the results of the 52-employee survey, most of the respondents (70%+) were aged 34 or above, and some 90% had at least a university degree. In the seven years prior to the survey, the company had implemented LM concepts and some of the basic tools mentioned. However, more than 80% of those surveyed did not know anything about I4.0, much less its tools.

Every change must involve all personnel to ensure successful implementation and appropriate feedback. As mentioned before, the communication of the "why", not just the "what" or the "how", is important. Most of time the implementation strategy (the "what" or the "how") changes, but "why" is always the same. After analyzing the perspective of various authors on the implementation of I4.0, and the reality of the work environment, as well as how the methodology of LM was first adopted, we identified a logical way (like roadmap methods) to align the current reality with the suggested steps for implementing I4.0.

After reviewing the challenges faced by different kinds of industries in Mexico regarding implementing I4.0, some scientific articles relevant to the railway sector were selected, in accordance with said challenges. Despite these challenges, many benefits were identified in the literature. Of all the benefits offered, the clearest ones are that it prevents falling behind in terms of current market needs and ensures that stakeholders are satisfied with the product or service.

To implement I4.0, as previously mentioned, it is first necessary to determine the current state of play, perform a SWOT analysis, and involve people who are key to the organization.

Sarvari, as cited by Ghobakhloo, states that this roadmap must contain every step on the route toward an entirely digital manufacturing enterprise. A roadmap is the center of the strategic agenda, to better time, visualize and understand each movement and decision [2]. This roadmap must contain short-, medium- and long-term goals, and must be consistent with the company's strategy.

To put together the company's strategy, it is necessary to perform a SWOT analysis, taking the short-, medium-, and long-term goals into account. These should then be implemented or cascaded along the entire value chain, with the focus being on added value to gradually eliminate all activities that do not add value. This should be applied to administrative activities as well as to shop-floor processes.

V. Conclusion

Technology plays a very important role in society. LM methodology has taught us to improve companies' processes and services by placing value on the needs of customers and stakeholders and eliminating wastes.

As a company or industry integrates technical innovation and market needs into its strategy to make a clear roadmap, it must include a SWOT analysis, establish short- medium- and long-term goals, then do an action plan to keep track of them and ensure accountability from all those involved. When implementing I4.0 (big data, IoT, the cloud, artificial intelligence) and LM, infrastructure, technical knowledge, methodology knowledge and leadership skills must be considered in the roadmap. I4.0 must be incorporated to benefit human talent and ensure that employees are well trained in all process improvements. Taking care of every part of the roadmap could help people's sense of achievement and appreciation, as shown in Fig. 6. All these technological changes should be included in school programs, to provide highly trained professionals who can adapt to the reality that companies increasingly face.

In Mexico, changes must be made to avoid being left behind due to the low-cost workforce, and to grow as a country in terms of the diversity of products and services that can be offered. I4.0 is becoming easier to incorporate due to technological advances and more competitive prices. The

biggest barriers are possibly ignorance and a lack of research and development strategies, so companies must work harder to obtain resources to overcome these barriers.

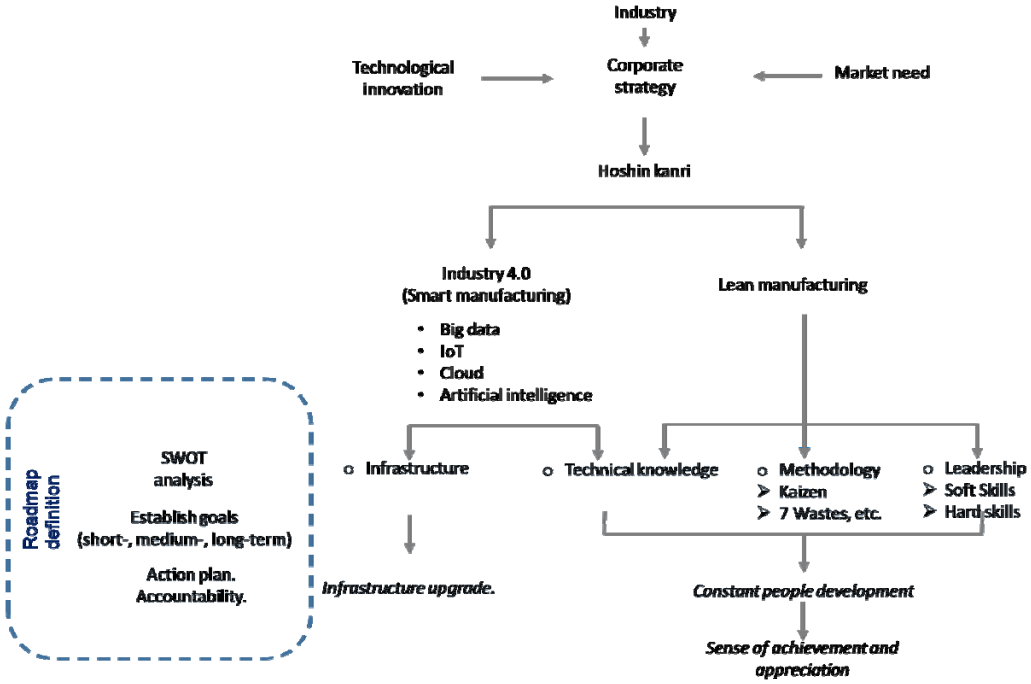

Fig. 6 Incorporation of principles and needs to properly implement I4.0 and Lean Management

There is a lot of scope for the Rail Manufacturing Process to adopt both LM and I4.0. Unfortunately, there is not enough information on cases specific to the Rail Manufacturing Process. Therefore, there is a wide scope for research in this field.

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