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Role of Lean manufacturing tools on economic sustainability in the Mexican manufacturing industry

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Abstract

Maquiladora companies apply lean manufacturing (LM) to reduce waste generated in their production process. This paper presents a structural equation model in which three LM tools (cellular manufacturing (CM), total productive maintenance (TPM), and just in time (JIT)) are related to economic sustainability (ES) using six hypotheses. The partial least squares technique evaluates the model with 239 responses to a survey applied to Mexican maquiladora companies. Based on this, a sensitivity analysis based on conditional probabilities is reported. The results indicate that CM facilitates the implementation of JIT and TPM and strengthens the ES of the maquiladora companies. The sensitivity analysis suggests that managers should generate an environment conducive to applying CM and TPM, as they are vital tools that facilitate obtaining ES. In addition, low levels of CM, JIT, and TPM are a high risk for achieving ES objectives.

Keywords: Cellular manufacturing; TPM; JIT; Economic sustainability.

1. Introduction

Cross-border trade is the economic engine along the U.S.-Mexico border, and the maquiladora industry has been its largest labor sector for decades (Cañas, Coronado, Gilmer, & Saucedo, 2013). The maquiladora concept emerged as a new model of manufacturing operations along the U.S.-Mexico border in the 1960s. Maquiladoras seek to lower labor costs by importing and processing raw materials to Mexico, and export them as finished products back to the country of origin, taking advantage of tariff preferences, skilled and low-cost labor (Dorocki & Brzegowy, 2014). & Brzegowy, 2014).

There are 5,171 maquiladoras in Mexico, many of them located in the northern border region due to their proximity to the United States of America (border) and Canada. One of the most critical border cities is Ciudad

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Juárez since there are 329 maquiladora companies there, equivalent to 66.73% at the state level. They generate 321,824 jobs in the city, equal to 11% at the national level (IMMEX, 2021a). In addition, by April 2021, Ciudad Juarez imported a total of 1,631 billion dollars and exported a total of 1,296 billion dollars (IMMEX, 2021b).

In 2020, Ciudad Juárez consolidated its position as the fifth place in attracting investment projects, hence the importance of the maquiladora industry. These maquiladoras have high technological levels and use tools for production optimization to compete in the global market. They focus on reducing non-value-adding activities, eliminating waste, and reducing setup time to remain competitive (Parwani & Hu, 2021). One approach that helps achieve that goal is Lean Manufacturing (LM), whose principles focus on attaining perfection through continuous improvement to eliminate waste by classifying activities that add value and activities that do not (Sundar, Balaji, & Kumar, 2014).

The sources of waste are transportation, inventory, waiting for movement, overproduction, over-processing, and defects (Sundar et al., 2014). By reducing waste, LM contributes to economic and social sustainability (Kumar, Mathiyazhagan, & Mathivathanan, 2020). LM focuses on designing a robust production operation that is responsive, flexible, predictable, and consistent to create a manufacturing operation focused on continuous improvement with customer focus (Feld, 2000).

There are a set of LM tools that help the decrease or elimination of those activities that do not add value, and according to Chiarini (2014), two of the essential tools are total productive maintenance (*TPM*) and cellular manufacturing (*CM*). *TPM* is an equipment maintenance plan widely used in the manufacturing industry to reduce losses in production activities, increase the lifetime of equipment and ensure its effective utilization (Nallusamy & Majumdar, 2017).

Cellular manufacturing system has emerged as an innovative and successful strategy in manufacturing systems for medium volume and variety productions. It is derived from the concept of cluster technology and brings together the advantages of flexible and mass production approaches (Mohammadi & Forghani, 2016). In *CM*, similar parts or products are grouped to create families. At the same time, the required work machines compose manufacturing cells intending to reduce production time, setups, work-in-process, increasing quality and system productivity (Defersha & Chen, 2006).

Likewise, tools such as just-in-time (*JIT*) also help to reduce non-value-adding activities. *JIT* is a systemic approach to developing and operating a manufacturing system (Alawode & Ojo, 2010) to meet customer demand quickly and with higher quality (G. Singh & Ahuja, 2015). It is based on delivering raw materials when they are needed and producing products when required (J. L. García-Alcaraz et al., 2016) and reducing waste in the production process (Pinto, Matias, Pimentel, Azevedo, & Govindan, 2018).

Research associated with *CM*, *TPM*, and *JIT* analysis and implementation can be found in the literature; for example, Pattanaik and Sharma (2009) propose a methodology for cellular distribution to apply lean concepts where the production flow between cells is optimized and waste time is reduced. Iqbal and Al-Ghamdi (2018) report 25% savings in energy consumption by setting up a cellular manufacturing system in a machining shop. Ahuja and Khamba (2007) establish the long-term effects of *TPM* on organizational performance in India.

Konecny and Thun (2011) investigate the impact of *TPM* and TQM supported by human resource practices on firm performance and indicate that these tools improve company performance. Still, the simultaneous application of both concepts does not necessarily lead to superior performance. Gupta and Garg (2012) study the effectiveness and application of *TPM* in an automobile manufacturing organization. K. Singh and Ahuja (2020) analyze *TPM* in synergy with TQM in achieving benefits such as customer satisfaction, reliability, productivity, and market share in Indian companies. Martínez-Loya, Díaz-Reza, García-Alcaraz, and Tapia-Coronado (2018) analyze the impact of *TPM* on work culture and profits in the maquiladora industry in Mexico. Díaz-Reza et al. (2018) analyze the impact of management on implementing *TPM*, Preventive Maintenance, and productivity benefits in the Mexican maquiladora industry.

In relation to *JIT*, J. García-Alcaraz, Maldonado, Alvarado Iniesta, Cortes Robles, and Alor Hernández (2014) analyze the application of *JIT* in the maquiladora industry, García, Rivera, Blanco, Jiménez, and Martínez (2014) relate *JIT* to organizational performance, and J. L. García-Alcaraz et al. (2015) associate the role of human resources in the implementation of *JIT*.

As can be seen, there is literature with information on using these LM tools in different industry sectors and different countries. However, no literature analyzes the relationship between *CM*, *TPM*, *JIT*, and economic sustainability in companies in northern Mexico, even with the importance of the maquiladora sector. For this reason, the objective of this work is to measure the effect of these LM tools on the economic sustainability of the maquiladora industry in northern Mexico, more specifically, in Ciudad Juarez, using structural equation modeling.

2. Literature Review and Hypothesis

2.1 Cellular manufacturing (*CM*)

CM is recognized as one of the promising approaches for production time reduction, especially when flexibility is prioritized in handling a complex product mix (Wu, Zhao, Feng, Niu, & Xu, 2021). The main characteristics of *CM* systems are that cells are arranged in parallel. Each cell is equipped with several heterogeneous machine types for multiple processes and products (Yin, Stecke, Swink, & Kaku, 2017) and dedicated to producing a set of part families per machine group (Yin & Yasuda, 2006).

To measure the *CM* implementation level, the sequence of material flow, the distance between one machine and another, the ease with which workstation layouts are changed, and how machines and devices are moved to integrate with other processes are observed.

2.2 Total productive maintenance (*TPM)*

TPM is accepted as the most effective maintenance strategy to improve performance, optimize equipment, eliminate breakdowns, and promote autonomy with the participation of all employees. *TPM* encompasses preventive and improvement-related maintenance intending to avoid losses and waste (Hooi & Leong, 2017). Moreover, it prepares companies to face challenges to compete globally and achieve world-class manufacturing (R. K. Sharma, Kumar, & Kumar, 2006). The level of machine availability, ease of machine relocation, breakdown aids, order, cleanliness in the workplace, and days spent on *TPM* are investigated to measure the *TPM* implementation in the industry.

Machines are the components of a cellular manufacturing system, subject to deterioration associated with use and age, leading to reduced product quality and increased production costs. Therefore, companies should establish preventive maintenance policies to improve a cellular manufacturing system (Das, Lashkari, & Sengupta, 2007). In that sense, *TPM* initiatives can be effectively integrated with *CM* to optimize performance improvement and, ultimately, competitiveness (Turbide, 1995). In that sense, the following hypothesis is established:

H_1: Cellular manufacturing has a direct and positive effect on total productive maintenance.

2.3 Just in time (JIT)

JIT seeks to meet customer requirements by offering perfect quality and zero waste (Pinto et al., 2018). Thus, in each more competitive environment and as a minimum requirement for survival, manufacturing companies must increase their capacity to produce top-quality products at the lowest cost and in the required time (Thomopoulos, 2016). inventory turnover and level, on-time order fulfillment, and absence of waste in the production process are investigated to measure *JIT* implementation in the industry.

CM provides a production infrastructure that facilitates the successful implementation of modern manufacturing technologies such as *JIT* (Gallacher & Knight, 1986). Implementing JIT reduces setup times, work-in-process inventory, material handling cost (Kia, Khaksar-Haghani, Javadian, & Tavakkoli-Moghaddam, 2014; Shanker & Vrat, 1999). i.e., *CM* is a manufacturing philosophy that facilitates the implementation of *JIT*, and then the following hypothesis is established:

H_2: Cellular manufacturing has a direct and positive effect on *JIT*.

The conception of *TPM* was a response to the demands of an increasingly competitive market that forced companies to outline some attitudes, such as: eliminate waste, always obtain the best performance of equipment and reduce interruptions or production stops (Teeravaraprug, Kitiwanwong, & SaeTong, 2011). *TPM* significantly affects and facilitates the level of *JIT* production implementation since as the burden of sudden machine breakdowns decreases, the level of on-time deliveries increases (Abdallah & Matsui, 2007). In that sense, implementing a *TPM* program is essential for lean production based on *JIT* (Arbós & Martínez, 2010), so the following hypothesis is proposed.

H_3: *TPM* has a direct and positive effect on *JIT*.

2.4 Economic sustainability (*ES*)

Rapidly changing market requirements call for improving company performance by focusing on cost reduction, increasing productivity levels, quality, and on-time delivery to satisfy customers (Jain, Bhatti, & Singh, 2014). Nowadays, customers are aware of the deterioration of the global environment and the foreseeable scarcity of natural resources in the future, so manufacturing companies are forced to change the paradigms of their systems to adapt to the new sustainability needs (Bi, 2011). LM practices are positively associated with various sustainability outcomes, such as economic, environmental, and social (MP, PR, A, & P, 2017). For example, improved operational performance such as lead time, speed, quality, and flexibility are associated with cost reduction (Khanchanapong et al., 2014), impacting financial results (Hofer, Eroglu, & Hofer, 2012). Therefore, when companies implement LM, they obtain economic sustainability (Resta, Dotti, Gaiardelli, & Boffelli, 2016).

Through *CM* and a particular U-shape, cell workstations and machines are placed close to each other to save space and time. In this way, material handling and transportation can be easily reduced and reduce energy consumption (Chiarini, 2014). Also, part family formation and machine clustering have some advantages, such as reducing setup times, material handling costs, work-in-process (WIP) inventories, production times, and production costs (Rabbani, Farrokhi-Asl, & Ravanbakhsh, 2019), so the following hypothesis is proposed:

H_4: Cellular manufacturing has a direct and positive effect on Economic sustainability.

Equipment maintenance is an essential function for companies. It improves productivity, labor, and equipment efficiency; that is why they should consider it a potential source of cost savings and competitive advantage (Jain et al., 2014). The successful implementation of *TPM* includes lower operating costs and lower overall maintenance costs (Inderpreet P Singh Ahuja & Khamba, 2008). According to Resta et al. (2016), the implementation of *TPM* brings economic benefits due to high efficiency and higher quality. In that sense, the following hypothesis is put forward:

H_5: *TPM* has a direct and positive effect on Economic sustainability.

One of the objectives of *JIT* is the control of lead time since through the management of lead time and optimal order quantity, inventory is minimized (Vijayashree & Uthayakumar, 2016). Through the implementation of *JIT*, costs can be reduced through less work-in-process, stock, shorter lead time, and less space occupied (Resta et al., 2016). Likewise, on-time delivery of production orders generates greater confidence in the producer and customer loyalty, so their sales and economic benefits increase (García-Alcaraz et al., 2016). Thus, the following hypothesis is proposed:

H_6: *JIT* has a direct and positive effect on Economic sustainability.

Figure 1 graphically illustrates the proposed relationships as hypotheses.

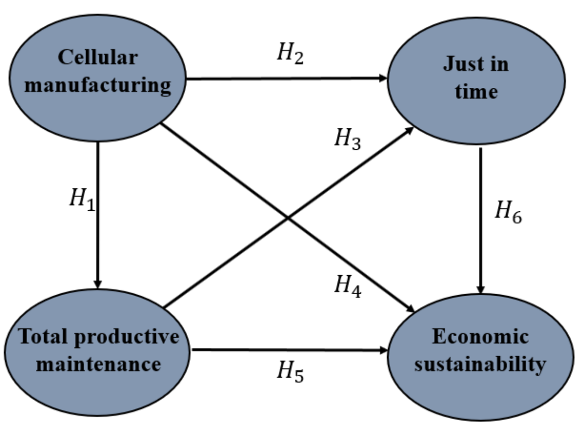

Figure 1. Proposed model

3. Methodology

3.1 Questionnaire design

A questionnaire is designed to validate the model in Figure 1through a literature review in databases such as ScienceDirect, Springer, and Emerald Insight to identify LM tools and benefits obtained. The search is performed using the names in LM tools to identify the critical activities for their implementation.

At the end of the literature review, five items were used for *CM*, seven for *TPM*, five for *JIT*, and eight for economic sustainability. The items should be answered on a 5-point Likert scale (one means that the activity is not performed, or the benefit is not obtained, while five indicates that the activity is always performed, or the benefit is obtained). Intermediate values are used for ratings such as rarely, regularly, and almost always.

3.2 Questionnaire administration

In the application of the questionnaire, the sample was identified with the help of the maquiladora association (AMAC) of Ciudad Juarez (Mexico). The inclusion criteria are as follows: responders must have at least two years in their current job position, be involved in LM tools implementation here analyzed, and preferably responders should be associated with the production and maintenance departments. These criteria procedures avoid bias data collection.

The application of the questionnaire is carried out in the period January-June 2020 through a specialized electronic platform. Potential respondents are sent an e-mail with an invitation to participate and a link to the questionnaire. If they did not answer after two weeks, they were sent another invitation, and if after this second one they did not answer, that case was discarded.

3.2 Data screening

A database is downloaded in the SPSS 25® software to debug the database and identify extreme values. For this, items are standardized, and values greater than four in absolute value are replaced by the median (Hoffman, 2019). Likewise, uncommitted respondents are identified by calculating the standard deviation, where if the value is below 0.5, that case is eliminated (N. Kock, 2019).

3.3 Descriptive analysis of the sample

Crosstables are made to identify the percentage of participation of the different industrial sectors and their size. In addition, the positions and experiences of each of the participants are analyzed.

3.4 Latent variable validation

The latent variables are validated using the indexes recommended by (Kock, 2020). The R^2 and adjusted R^2 indices measure parametric predictive validity, which accepts values greater than 0.02. Q^2 index is used to measure nonparametric predictive validity, and values greater than zero and similar to R^2 are recommended. Cronbach's alpha and composite reliability indexes measure internal reliability and composite reliability, whose minimum acceptable values are 0.7.

The average extracted variance is calculated to measure convergent validity and values greater than 0.5 are recommended. Finally, the variance inflation index (VIF) is estimated to measure collinearity, and values less than 0.5 are accepted.

3.5 Structural equation model

A structural equation model (SEM) using the partial least squares technique in WarpPLS 7.0® Software (Kock, 2017; Ned Kock, 2019; Kock, 2020). is used to validate the hypotheses in Figure 1. This technique has been used to model lean manufacturing tools in the maquiladora industry such as SMED (Díaz-Reza et al., 2016; Díaz-Reza et al., 2017), *JIT* (Alcaraz, Maldonado, Iniesta, Robles, & Hernández, 2014), *TPM* (Díaz-Reza et al., 2018).

To validate the model, the following model fit, and quality indices are used (Kock, 2020): Average Path coefficient (APC) for the general validity of the model ($P<0.05$), Average R^2 (ARS) and, Average Adjusted R^2 (AARS) ($P<0.05$), Average block VIF (AFVIV) to measure collinearity between latent variables should be less than five. Finally, the Tenenhaus Goodness of Fit (GoF) index to measure model fit must be greater than 0.36.

Three types of effects are analyzed in the SEM. The direct effects are identified by arrows in Figure 1 and represent the proposed hypotheses tested at a significance level of 0.05. A standardized β is assigned to each effect, and H_0: $\beta = 0$ is tested against H_1: $\beta \neq 0$. If H_0 is rejected, it is concluded that there is a direct relationship between the variables. Indirect effects occur through mediating variables, i.e., they are effects of two or more arrow segments. For these indirect effects, a value of β is also obtained, to which a significance level of 0.05 is associated. Finally, the total effects are obtained, whose values are the direct effects plus the indirect effects. A value of β is estimated, and a p-value is associated with them.

3.6 Sensitivity analysis

A sensitivity analysis is performed to calculate the probabilities of high and low scenarios of the latent variables. A high scenario is represented by $P(Z_i>1)$ and a low scenario by $P(Z_i<-1)$. Three probabilities are reported that the variables occur in their high or low level independently. The variables can occur jointly in their high and low levels and are represented by "&." The probability that a dependent variable appears in a scenario given that an independent variable has happened in a specific scenario and is represented by "IF."

4. Results

4.1 Descriptive analysis of the sample and descriptive analysis of the items

A total of 239 valid questionnaires were obtained from the application of the questionnaires, of which 76 were women and 163 were men. The participating sectors were automotive with 139, electrical with 14, electronics with 26, logistics with 9, machining with 23, and medical with 28. Table 1 shows the size of the companies in which each of the participants works and the position they hold. The companies that participated the most were companies with between 1000 and 5000 workers with 88. It can also be seen that most people are production managers (125) and maintenance managers (80).

Table 1. Job position and number of employees

Job position	Number of employees						Total
	<50	50 - < 300	300- <1000	1000 - <5000	5000- <10000	>10000	
Maintenance Manager	13	12	13	32	6	4	80
Production Manager	10	17	28	47	10	13	125
Maintenance Engineer	5	4	8	9	3	5	34
Total	28	33	49	88	19	22	239

4.2 Latent variable validation

Table 2 shows the validation of each of the latent variables. It is observed that there is sufficient parametric predictive validity since the values of R^2 and adjusted R^2 are greater than 0.02, and nonparametric predictive validity since Q^2 has values greater than zero and similar to R^2. It is concluded that there is internal validity since composite reliability and Cronbach's alpha are greater than 0.7; in addition, there is convergent validity since the AVE index is greater than 0.5. Finally, there are no collinearity problems since the values of VIF and AFVIF are less than 5.

Table 2. Latent variable validation

Index	*CM*	*TPM*	*JIT*	EC
R^2		0.35	0.501	0.59
Adjusted R^2		0.347	0.497	0.585
Cronbach´s alpha	0.86	0.923	0.891	0.946
Composite reliability	0.783	0.902	0.817	0.933
Average variance extracted (AVE)	0.606	0.632	0.732	0.714
Full collinearity VIF	2.007	2.257	2.092	2.403
Q^2		0.346	0.503	0.591

4.3 Structural equation model

The fit and quality indices of the model are shown below. It can be observed that there is an average of 0.378 in the path coefficient, i.e., the average value of the direct effects is 0.378 with a p-value of less than 0.05, which makes them statistically significant. Concerning the ARS and AARS coefficients, it is observed that they have values of 0.481 and 0.476, respectively. Therefore, the model has sufficient predictive validity. There are no collinearity problems since the AVIF and AFVIF indices have values of 1.770

and 2.190, respectively. Finally, it is observed that the model fits the data since the Tenenhaus GoF index is 0.568, so the model has explanatory power.

The values in the indices are APC=0.378 (P<0.001), ARS = 0.481 (P<0.001), AARS=0.476 (P<0.001), AVIF=1.770 (acceptable if≤5), AFVIF=2.190 (acceptable if≤5) and GoF=0.568 (large≥0.36). Given that the model meets the indices, we proceed to its interpretation.

Figure 2 shows the direct effects (β), the associated p-values, and R^2. According to the p-values, it is concluded that all hypotheses are statistically significant and that the largest effect occurs between the variables *CM* and *TPM* with a β = 0.592; that is, if *CM* increases its standard deviation by one unit, *TPM* will do so by 0.592 units. Furthermore, the size of their effect or the variance explained by *CM* on *TPM* is 0.350. In other words, the first variable explains the second by 0.350.

The above allows concluding that it is easier to implement a total productive maintenance system if CM activities are adequately developed. There will be a higher inventory turnover, the necessary raw material, production orders will be delivered in the estimated time, the machinery will work as planned, and there will be no waste in the process. In other words, if the activities are carried out correctly in *CM*, companies will work with a just-in-time philosophy since *CM* accounts for 0.258 of *JIT*.

Table 3 summarizes the effects presented in the model in Figure 2 (direct, indirect, and total effects) and the size of each of these. For indirect effects, *CM* has an indirect effect on *ES* through *TPM* and *JIT* of 0.381, with a size of 0.242. These values indicate that the activities in *CM* directly affect *TPM* and *JIT*, but in turn, on *ES* through these two. In other words, if *CM* contributes directly and positively to developing *TPM* programs and the *JIT* philosophy, then it will bring *ES* to the maquiladoras.

Regarding the total effects, it can be concluded that the variable that contributes most to obtaining *ES* is *CM* with an effect size of 0.403, followed by *TPM* with 0.358 and *JIT* with 0.125. *CM* has *TPM* and *JIT* as mediating variables, and its effect on *ES* grows because *CM* directly affects *TPM* and *JIT*, which, in turn, contributes to *ES*.

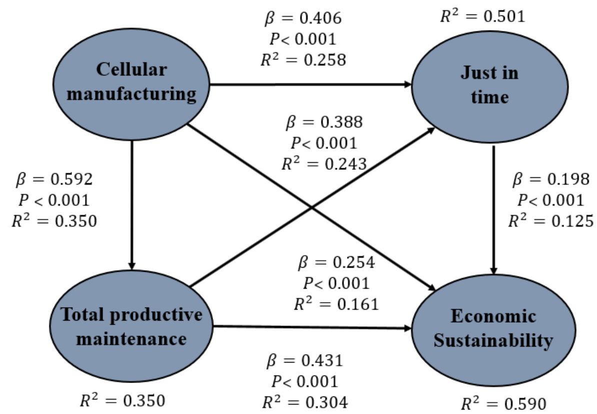

Figure 2. Evaluated model

Table 3. Effect's overview

Hypotheses	Effect β (p-value)			Effect size		
	Direct	Indirect	Total	Direct	Indirect	total
H_1 *CM* → *TPM*	0.592 P<0.001		0.592 P<0.001	0.35		0.35
H_2 *CM* → *JIT*	0.406 P<0.001	0.229 P<0.001	0.635 P<0.001	0.258	0.146	0.404
H_3 *TPM* → *JIT*	0.388 P<0.001		0.388 P<0.001	0.243		0.243
H_4 *CM* → *ES*	0.254 P<0.001	0.381 P<0.001	0.635 P<0.001	0.161	0.242	0.403
H_5 *TPM* → *ES*	0.431 P<0.001	0.077 P=0.045	0.508 P<0.001	0.304	0.054	0.358
H_6 *JIT*→ *ES*	0.198 P<0.001		0.198 P<0.001	0.125		0.125

4.4 Sensitivity analysis

Table 4 shows the sensitivity analysis for each of the proposed relationships. The "Level" row/column shows the high (+) and low (-) scenarios for each of the variables. The probability of these variables occurring in isolation in that scenario is shown in the probability row/column. The crossing of one variable and the other shows the scenario in which both probabilities occur jointly (&) and conditionally (if).

For example, for hypothesis H_1 the probability that *CM* is presented in its high scenario (*CM*+) or that the activities in that variable are performed above the average is 0.172, and performed below (*CM*-) the average is 0.155. The probability that *TPM* will occur at its high level (*TPM*+) is 0.142 and that it will appear at its low level (*TPM*-) is 0.163. The probability that they will occur jointly at its high level (*TPM*+ & *CM*+) is 0.079, and that they will occur jointly at its low level (*TPM*- & *CM*-) is 0.092. That is, the probability that the activities are performed correctly together is very low. However, if the managers who are the leaders of each area ensure that these *CM* activities are performed correctly, in that case, there is a conditional probability of 0.463 of having a proper *TPM* implementation. Conversely, suppose the leaders do not ensure that this happens. In that case, there is a conditional probability of 0.595 that *TPM* will not be adequately performed and, consequently, the *ES* sought by the companies will not be obtained.

Table 4. Sensitivity analysis

Level		*CM+*	*CM-*	*TPM+*	*TPM-*	*JIT+*	*JIT-*
	Probability	0.172	0.155	0.142	0.163	0.188	0.130
TPM+	0.142	&=0.079 If=0.463	&=0.000 If=0.000				
TPM-	0.163	&=0.008 If=0.019	&=0.092 If=0.595				
JIT+	0.188	&=0.084 If=0.488	&=0.004 If=0.027	&=0.088 If=0.618	&=0.013 If=0.077		
JIT-	0.130	&=0.008 If=0.049	&=0.067 If=0.432	&=0.004 If=0.029	&=0.079 If=0.487		
ES+	0.146	&=0.071 If=0.415	&=0.000 If=0.000	&=0.075 If=0.529	&=0.008 If=0.051	&=0.075 If=0.400	&=0.000 If=0.000
ES-	0.167	&=0.004 If=0.024	&=0.092 If=0.595	&=0.000 If=0.000	&=0.096 If=0.590	&=0.004 If=0.022	&=0.075 If=0.581

5. Conclusions

According to the structural equation model, the following can be concluded concerning the hypotheses:

CM has a direct and positive effect on TPM of β=0.592 with R2=0.350 (H1); also, CM has a direct and positive effect on JIT of 0.406 with R2=0.258 (H2); and finally, CM has a direct and positive effect on ES with a β=0.254 with R2=0.161 (H4). The above implies that CM as workstations design facilitates material handling and TPM implementation because the maintenance managers and operators are skilled persons in specific machines. Also, given that machinery and devices have a high availability level because they rarely have downtimes, JIT is easily implemented. In addition, CM operating centers where TPM and JIT are implemented will obtain ES by reducing production costs, energy costs, inventories, customers' rejects, rework, raw material, and waste treatment.

TPM affects JIT of β=0.388 with an R2=0.243 (H3) and ES with a β=0.431 and an R2=0.304 (H5). The above implies that TPM influences JIT and on ES, but of greater size on the latter. If companies perform preventive maintenance, they ensure that machines will have high availability for production. Also, implementing Andon systems will facilitate the JIT implementation and, in addition, will be an enabler to the reduction of production cost, energy cost, inventory level, reject rates, rework and reprocess rate, raw material, and waste treatment costs.

JIT has a direct effect on ES of β=0.198 and R2=0.125 (H6), which reflects the dependence of ES. This relationship implies that if there is a constant inventory turnover, if only what is needed by customers are manufactured in the estimated time, and no waste is generated, then there will be ES by reducing costs. It is essential to point out the indirect effects of CM and TPM on ES through JIT, which indicates that CM and TPM contribute to the ES of the companies since they are JIT enablers.

According to the sensitivity analysis and different scenarios for latent variables, the following is concluded:

In this model, CM is an LM tool that affects all other variables. When CM+ is present, there is a conditional probability of 0.463 that TPM+ is obtained, indicating that CM facilitates TPM; however, CM+ is not associated with TPM-, as the probability is close to zero. Furthermore, if CM- is present, there is a 0.595 probability of obtaining TPM, representing a risk for managers. Finally, it is observed that CM- is never associated with TPM+ since the probabilities are zero. In other words, CM facilitates the implementation of TPM in manufacturing industries, and managers should seek to have this type of machine layout in their production lines.

It is observed in the sensitivity analysis that if maquiladora companies have a CM+ system, then they have a 0.488 probability of JIT+ occurring, indicating that CM facilitates the JIT implementation; however, CM+ is only weakly related to JIT-, since the conditional probability is only 0.049. On the contrary, if CM is present, only a 0.027 conditional probability of JIT+ occurs, but a 0.432 probability of JIT- occurring. This relationship indicates that managers should focus on having a CM-based plant layout to reap the benefits of JIT.

Although CM has been shown to facilitate the implementation of TPM and JIT, the most critical analysis is when it is related to ES. If CM+ occurs, then there is a 0.415 probability that ES+ will be obtained, which convinces any manager; however, CM+ is not related to ES -, as the conditional probability is only 0.024, which confirms the above assertion. This positive relationship between the variables is established by observing that CM- is never associated with ES+, but if CM- maintains the same scenario, then there is a 0.595 probability of ES- occurring. In conclusion, CM guarantees SE in manufacturing industries.

One of the most important relationships is when TPM+ occurs; since then, there is a 0.618 probability of JIT+ occurring; however, TPM+ is not associated with JIT+, since the conditional probability is only 0.029, the high positive relationship between the two variables. Furthermore, if TPM- occurs, then there is a 0.077

probability that JIT+ occurs, indicating that other factors are supporting the latter variable; however, if TPM- occurs, then there is a 0.487 probability that JIT- occurs. In conclusion, it can be said that TPM is a tool that supports JIT in manufacturing industries.

TPM is also directly related to ES. It is observed that if TPM+ is present, then there is a probability of 0.529 that ES+ occurs; that is, TPM facilitates ES in the maquiladora industries, and that statement is verified by reviewing that TPM+ is not related to ES -, since the conditional probability is null. However, if TPM- occurs, then there is a 0.051 probability of ES+ occurring, indicating that other LM tools support ES; furthermore, if TPM- occurs, then there is a 0.590 probability of ES- occurring, which represents a risk for managers.

Although many authors have indicated the relationship of JIT with the financial aspects of the companies, in this study, it is observed that if JIT+ occurs, then there is a conditional probability of 0.400 that ES+ appears. It is observed that JIT is not associated with ES -, since the conditional probability is only 0.022. However, if JIT occurs in the manufacturing industry, then there is a null probability that ES+ occurs, reaffirms the previous assertion. Finally, it is observed that if JIT- occurs, then ES- can occur with a chance of 0.581.

Future research

This paper presents a structural equation model in which four latent variables are integrated and related using six hypotheses. However, it has been found that the dependent variables are not fully explained, so the following lines of research will be pursued in future work:

1. Integrate other LM tools implemented simultaneously in the production lines, such as SMED and Kanban, that support JIT, or integrate social and environmental sustainability.
2. Simulate through system dynamics the different scenarios that can be had for the different variables since there are indeed established probabilities of occurrence.

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