Material Flow in Production Process its Effect on Economic Sustainability

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Abstract

This paper reports a structural equation model in which total productive maintenance (TPM), just-in-time (JIT), overall equipment efficiency (OEE) indexes are analyzed as latent independent variables how they affect the economic sustainability (ES) of the companies through the flow of materials their disruptions. The variables are related using six hypotheses in the model, evaluated with information from 239 responses to a questionnaire applied to the Mexican maquiladora industry. The partial least squares technique is applied to validate these hypotheses. The results indicate that TPM is highly related to JIT, SE, OEE, likewise, JIT has a direct relationship with OEE SE. It is concluded that lean manufacturing tools applied to materials flow in a production system must be highly monitored to avoid disruptions that affect the economic income of companies.

Keywords
TPM, JIT, OEE, production system, lean manufacturing.

1. Introduction
Industrial companies play an essential role in the economic sustainability of countries society, so it is vital to manage their operational administrative practices correctly. Specifically, in Mexico, there are programs focused on improving the industry, resulting in foreign companies establishing subsidiaries in the national territory transforming raw materials, since it has a high level of skilled labor, proximity to the United States of America Canada; in addition, there are free trade agreements between these nations (García-Alcaraz et al., 2015). These subsidiary companies are called maquiladoras.

In December 2021, Mexico had 5188 maquiladora companies throughout the country, of which 487 were located in the state of Chihuahua, with Ciudad Juarez being the most represented region with 322 industries, equivalent to 6.2% nationally (INDEX, 2022b). These companies in Ciudad Juarez employ 327,253 workers, which reflects the importance of this sector within the regional economy society (INDEX, 2022a).
These industries apply different philosophies in their production lines supply chain to survive in the highly competitive markets, focusing their resources on alternatives that allow them to have effective processes, both in terms of saving materials without disruptions, shorter process times, waste reduction. One of the strategies is applying the lean manufacturing methodology, a set of tools to address problems associated with standardization, material flow, quality, integration of human resources. Thus, companies' benefits are reflected in their production processes, prevent disruptions that affect supply chains, promote economic sustainability (Jimenez et al., 2019).

Therefore, it is concluded that lean manufacturing provides industries with greater control of the planning execution of productive activities, considering a better use of available resources, both material, human, infrastructure, which prevents disturbances due to poor management of the goods it has. On the other hand, it is also involved in the decrease of the inventory, both of raw material finished product, due to the fluidity that it manages to have with good execution of tools, such as just in time (JIT), measurement of Overall equipment effectiveness (OEE) total productive maintenance (TPM) (Mohd Ghazali Maarof, 2016). For example, JIT integrates people infrastructure in a single approach, focusing on working in a single direction reducing waste in production processes. It uses studies that allow knowing the times taken in the different stages of product transformation until the product is in the conditions requested by the customer thus not having the product waiting in the warehouse inventory (Kim and Shin, 2019).

JIT is based on the study of the demto know the number of units necessary to produce manufacture only what the customer requires. This allows not having excess inventory that runs the risk of not being sold, which can affect the company's economic sustainability (Alcaraz, Maldonado, Iniesta, Robles, and Hernández, 2014). A JIT system for the flow of materials is useless if there are no machines tools in good condition that allow the flow of materials, so, to avoid disruptions, TPM programs are required. The main goal is to obtain a low probability of failures unplanned stops in the machinery. It uses plans that contemplate preventive maintenance that operators execute, decreasing idle time (Díaz-Reza et al., 2018). To achieve it, workers are trained to know the necessary actions for repairs adjustments of the machines avoid interruptions in their assigned tasks (Shen, 2015).

Other studies have shown in other sectors countries that TPM is associated with some sustainability; for example, Jahangir, Hasin, Bashar (2020) relate it to financial organizational performance; however, as mentioned by Alseiari, Farrell, Osman (2020), its implementation faces specific barriers, which can be material, human a follow-up control of it. One of the tools that help to support TPM is OEE since it is associated with machine availability, the quality it generates, performance. Thus, OEE is vital in the production planning process since it indicates the units produced in a cycle time determined by the industry that can be modified according to the demand.

OEE serves as a parameter also for the calculations required by JIT, since such planning focuses on the allocation of the production goal that is necessary to meet the demand, so it starts from that amount encompasses it with the available time (Heng, Aiping, Liyun, and Moroni, 2019). The integration of these tools ensures in general terms the flow of materials that avoid disruptions in the production process, which in turn affects the economic income of the company and, therefore, the economic sustainability, which represents one of the significant goals that companies have since it represents the cash flow that affects profits (Arya, Jaiswal, and Srivastava, 2019).

This article presents a structural equation model in which TPM, OEE, JIT are analyzed as dependent variables related to companies' economic sustainability. The objective is to quantify the variables' relationships indicate which of them are trivial to achieve ES.

2. Literature review hypotheses

2.1 TPM

TPM is a manufacturing program to maximize the efficiency of equipment over its useful life through the involvement motivation of operating personnel (Nakajima, 1988) Its objective is to continuously improve the production system, financial performance, profitability of organizations (Fullerton, Kennedy, and Widener, 2014; Seth and Tripathi, 2006); In addition, it seeks intra- interdepartmental commitment within an organization to maximize the overall effectiveness of production teams (Bakri, Rahim, Yusof, and Ahmad, 2012). TPM involves production maintenance personnel working as a team to reduce losses, downtime, improve the quality of the final product (Eti, Ogaji, and Probert, 2004) (Narusawa and Shook, 2009).

2.2 JIT

JIT is a production philosophy based on adding value eliminating waste. Value is added only by the work performed on the product, waste is anything other than a minimum amount of resources required for production does not add value to the product (Thomopoulos, 2016). JIT is considered a production system to manufacture deliver what is needed when needed in quantity needed (Narusawa and Shook, 2009).
TPM supports JIT efforts with reliable equipment that improves delivery efficiency, speed, reliability (Ahuja and Khamba, 2008). To achieve world-class manufacturing status, implementing a TPM program is required to ensure

smooth operation under the constraints of a JIT production environment (Chand Shirvani, 2000). In other words, TPM is indispensable to maintain just-in-time operations (Ahuja, 2009) in that sense, the following hypothesis is put forward:

H_1: TMP has a direct positive impact on JIT.

2.3 OEE

OEE provides a quantitative metric based on the elements of availability, throughput, quality to measure the performance efficiency of individual equipment or entire processes (Garza-Reyes, 2015). OEE is a measure of the value added to production through equipment, a function of machine availability, throughput efficiency, quality index(Chand Shirvani, 2000). OEE is the primary metric for measuring the success of the TPM implementation program (Jeong and Phillips, 2001; Singh, Gohil, Shah, and Desai, 2013).

TPM initiatives provide a periodic measurement of OEE, monitoring, performance improvement, guidelines to achieve higher productivity (Kumar, Kumar Soni, and Agnihotri, 2014). By implementing some preventive, corrective, autonomous maintenance activities, machinery stoppages are reduced, thus improving its availability and, at the same time, increasing OEE (Pinto et al., 2020). n this sense, the following hypothesis is proposed:

H_2: TPM has a direct positive impact on OEE.

OEE is one of the measures to determine the overall effectiveness of equipment by determining the deviation from the target of zero defects zero breakdowns (Ribeiro et al., 2019). EE management in the manufacturing industry is an essential strategy for continuous improvement of on-time delivery service quality to meet customer satisfaction their expectations (Esmaeel, Zakuan, Jamal, and Taherdoost, 2018b). In this regard, the following hypothesis can be put forward:

H_3: OEE has a direct positive impact on JIT.

2.4 Economic Sustainability (ES)

Sustainability is considered a method to determine the ranking of economic opportunities over time (Chichilnisky, 2011). ES affects environmental social sustainability through the provision of capabilities to develop a higher level of education a healthy environment for society (Esmaeel, Zakuan, Jamal, and Taherdoost, 2018a).
Currently, sustainability is associated with manufacturing, which creates manufactured products that use non-polluting processes natural resources conserve energy, are economically sound safe for employees, communities, consumers (Esmaeel et al., 2018b). Then, reducing machine failures deterioration helps to reduce costs increase product quality (Melesse and Ajit, 2012) , that cost reduction positively affects the HE of the organization (Ahuja, 2009). Specifically, TPM is designed to avoid energy losses waste associated with machines tools (Longoni and Cagliano, 2015), so the following hypothesis is proposed:

H_4: TPM has a direct positive impact on Economic Sustainabilty

JIT encourages the utilization of less inventories, such as raw materials, work-in-process, final products, by eliminating waste (Agyabeng-Mensah et al., 2021), which reduces pollutant emissions, material, energy consumption (King and Lenox, 2001). In addition, JIT produces economic benefits due to the reduction of waste, movement, time (Bookbinder and Ülkü, 2021), so the following hypothesis is put forward:

H_5: JIT has a direct, positive impact on economic sustainability

The objective of OEE is to identify losses (availability, throughput rate, production quality rate) (Al-Najjar, Hansson, and Sunnegårdh, 2004) which include breakdowns, set-up, idle machines, minor stoppages, speed reduction, process defects, yield loss (Schippers, 2001). OEE incorporates these metrics to help manufacturing operations teams improve performance reduce cost(Ahuja and Khamba, 2008), so the following hypothesis is proposed:

H_6: OEE has a direct positive impact on economic sustainability.

Figure 1 shows graphically the hypotheses described above.

3. Methodology

3.1 Survey design

A survey was designed applied to managers engineers working in the Mexican maquiladora industry. The questionnaire is integrated into three sections; the first one refers to demographic data of the respondent, the second one to the lean manufacturing tools used by managers to guarantee the material flow, the third one to the economic benefits obtained from the implementation of these tools.

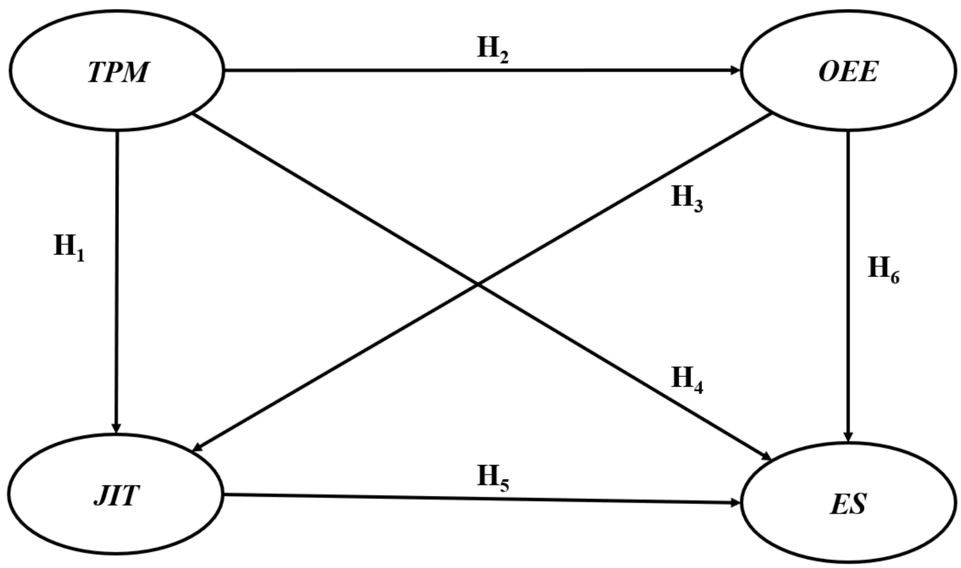


Figure 1. Proposed model

The lean manufacturing tools analyzed are TPM, JIT, OEE as independent latent variables, their items are integrated from previous research by Morales-García, Díaz-Reza, García-Alcaraz (2021), Suryaprakash, Gomathi Prabha, Yuvaraja, Rishi Revanth (2020) Sahoo (2019). The response variable is ES, its items are integrated from research by García-Alcaraz et al. (2021). Google forms platform is used to generate the questionnaire, a link is sent to potential respondents to be answered anonymously confidentially. Respondents must be in a managerial position to know the benefits of implementing LM techniques how they affect material flow throughout the production process. The questionnaire was receiving responses from August 1 to December 1 all items should be given on a five-point Likert scale.

3.2 Data capture debugging

The Google form platform with the questionnaire remains open for three months, mass mailings are sent to potential respondents. At the end of the information reception period, an Excel file is downloaded in which the information is cleaned, where the median replaces missing extreme values. Also, to identify uncommitted respondents, the standard deviation of each item is obtained, eliminating those in which it is less than 0.5. In addition, the median of each item is obtained as a measure of central tendency the interquartile range (IQR) as a measure of dispersion.

3.3 Information validation

The variables in the model are validated based on the following indices: Cronbach's alpha composite validity index for internal validity, R2, adjusted R2 for parametric predictive validity, Q2 to measure nonparametric predictive validity, the variance extracted index (AVE) for convergent validity variance inflation index (VIF) to measure with linearity.

3.4 Structural equation model

If the variables meet the validation indices, they are integrated into a structural equation model to validate the proposed hypotheses. Before interpreting the model, it is validated using the following indices: Average path coefficient (APC) for the general validity on relationships, Average R-squared (ARS) Average adjusted R-squared (AARS) for the predictive validity, Average block VIF (AVIF), Average full collinearity VIF (AFVIF) to measure collinearity Tenenhaus index (GoF) to measure the data fit in the model.

Three types of effects between variables are estimated, direct effects that serve to statistically validate the hypotheses, the sum of indirect effects, total effects. All estimates are made with a confidence level of 95%. A standardized β value is obtained using the partial least squares technique integrated into WarpPLS 7.0® software to validate the hypotheses. The null hypothesis H0 $\beta=0$ is tested versus the alternative hypothesis H1 $\beta\neq0$. If it is statistically proven that $\beta=0$, it is concluded that there is no relationship between the variables analyzed, otherwise, it is concluded that there is (regardless of the sign).

A sensitivity analysis is also reported for the variables in the model, where it is assumed that a low scenario occurs when the standardized z value is less than -1, a high scenario is when z is greater than 1. Specifically, three probabilities are reported: the probability of the variables occurring in isolation in a high or low scenario, the probability of the variables occurring jointly in a combination of scenarios, the probability of the dependent variable occurring, given that the independent variable has occurred in any scenario.

4. Results Discussion

4.1 Sample description

A total of 238 responses were received as of December 1, 2021; 89 were from women 149 from men. The positions held by the respondents were managers (81), engineers (28), supervisors (34), technicians (96). The industry sectors were automotive (88), aeronautics (51), electrical (24), electronics (27), logistics (6), machining (11), medical (20), plastics (19).

4.2 Latent variables validation

Table 1 shows the validation indexes obtained for each latent variable analyzed. According to these values the criteria in the last column, all the variables pass the validation process are integrated into the structural equation model.

Table 1. Validation indexes

Index	TPM	JIT	OEE	ES	Best if
R^2		0.541	0.416	0.544	>0.02
R^2 adjusted		0.537	0.414	0.539	>0.02
Composite reliability	0.918	0.891	0.904	0.938	>0.7
Cronbach alpha	0.880	0.817	0.841	0.917	>0.7
AVE	0.736	0.732	0.759	0.750	>0.5
Q^2	2.158	2.228	2.405	2.159	>0.02

4.3 Structural Equations Model

Figure 2 illustrates the evaluated structural equation model, where the β value indicates the intensity of change between variables, the associated p-value means the statistical significance test for β, the R^2 value is the variance explained in the dependent variables. According to those p-values, Table 2 shows the conclusions obtained from the hypotheses initially proposed in the model in Figure 1 according to them, all hypotheses are statistically accepted because the values are lower than 0.05. An interpretation regarding the relationship between TPM JIT is as follow: There is enough statistical evidence to declare that TPM has a direct positive effect on JIT since when the first variable increases its standard deviation in one unit, the second one goes up by 0.298 units. Similar interpretations are given for other relationships hypotheses.

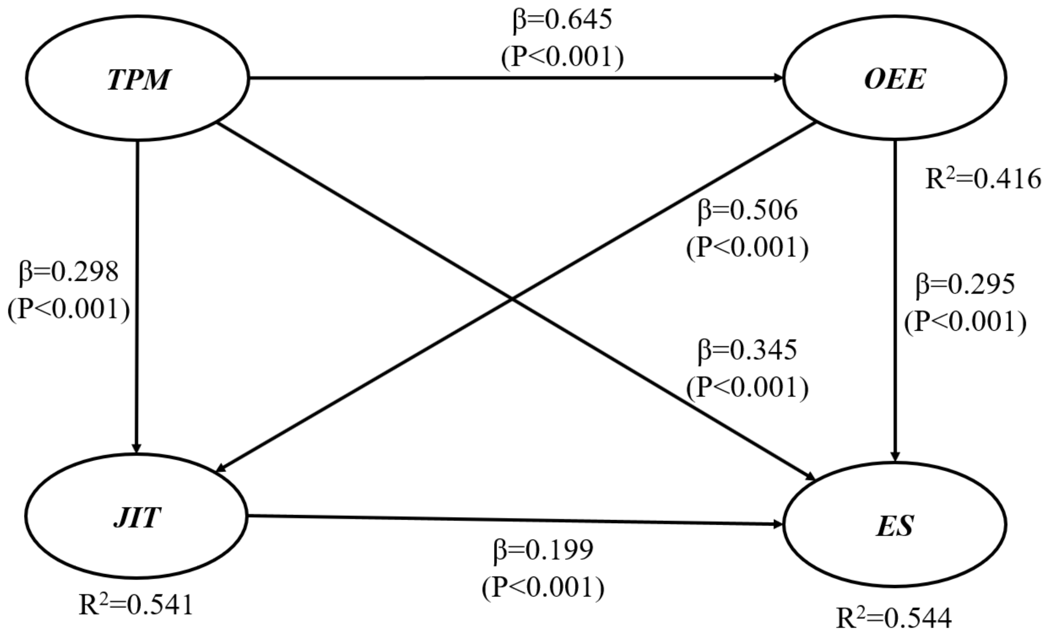


Figure 2. Structural equation model evaluated

Table 2. Hypotheses test

ILV	DLV	P value	β	Conclusion
TPM	JIT	<0.01	0.298	Accept
TPM	OEE	<0.01	0.645	Accept
OEE	JIT	<0.01	0.506	Accept
TPM	ES	<0.01	0.345	Accept
JIT	ES	<0.01	0.199	Accept
OEE	ES	<0.01	0.295	Accept

ILV: Independent latent variable, DLV: Dependent latent variable

Table 3 indicates the sum of indirect effects total effects (sum of direct indirect effects). As in the direct effects, the β values the p-values indicate a measure of the statistical significance test. According to those values, all indirect total effects are statistically significant. Specifically, the direct effect between TPM JIT was only 0.298, but the indirect effect that occurs through OEE is 0.326; that is, the indirect relationship is larger than the direct, so special attention should be paid to it. Similarly, the direct relationship of TPM with ES is only 0.345, but the indirect relationship through OEE JIT is 0.314, indicating that these tools cannot be applied independently.

Table 3. Sum of indirect total effects.

ILV	DLV	Indirect effects		Total effects	
		P value	β	P value	β
TPM	JIT	<0.001	0.326	<0.001	0.624
TPM	OEE			<0.001	0.645
OEE	JIT			<0.001	0.506
TPM	ES	<0.001	0.314	<0.001	0.660
JIT	ES			<0.001	0.199
OEE	ES	=0.013	0.101	<0.001	0.396

ILV: Independent latent variable, DLV: Dependent latent variable

Table 4 shows a matrix with graphs relating the independent variables (x-axis) the dependent variables (y-axis) for each hypothesis. It is observed that TPM is related to all the other variables increasing way, but the relationship is stronger with OEE, which is almost linear. It is observed that there is a small stagnation with the variable ES, but again it increases exponentially. A similar phenomenon occurs between OEE with JIT ES, as well as between JIT ES.

Table 4. Graphical relationships among variables

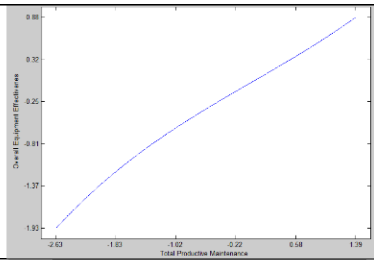
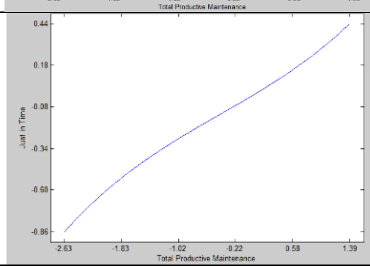
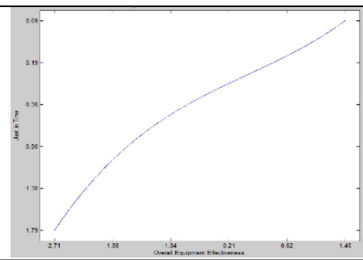
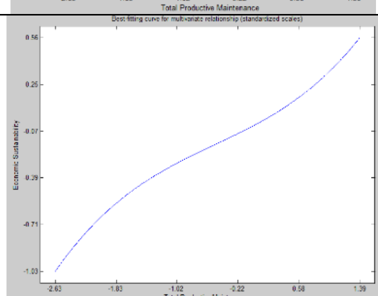
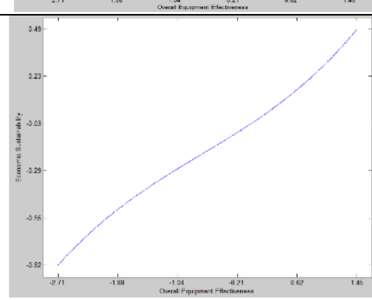
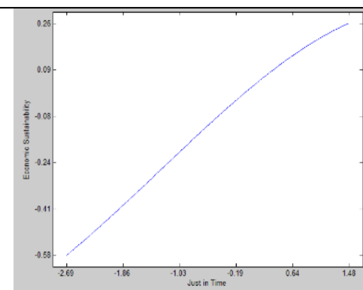
To	From		
	TPM	OEE	JIT
OEE			
JIT			
ES			

Table 5 indicates the probabilities obtained for the sensitivity analysis. High scenario levels are represented by the sign "+" low scenario levels by "-". The values indicate the isolated occurrence probabilities for each variable in its different scenarios, the joint probabilities indicated by "and " the conditional probabilities indicated by "If". Table 5 shows important values concerning the occurrence probabilities.

Table 5. Sensitivity analysis

			From					
			TPM		*OEE*		*JIT*	
To	Level	level	+	-	+	-	+	-
		Probability	0.138	0.167	0.188	0.151	0.188	0.13
OEE	+	0.188	and =0.084	and =0.008				
			If=0.606	If=0.050				
	-	0.146	and =0.004	and =0.096				
			If=0.030	If=0.575				
JIT	+	0.188	and =0.079	and =0.004	and =0.100	and =0.000		
			If=0.576	If=0.025	If=0.533	If=0.000		

	-	0.13	and =0.004	and =0.084	and =0.004	and =0.088		
			If=0.030	If=0.500	If=0.022	If=0.600		
ES	+	0.151	and =0.067	and =0.004	and =0.079	and =0.008	and =0.071	and =0.000
			If=0.485	If=0.025	If=0.422	If=0.057	If=0.378	If=0.000
	-	0.138	and =0.000	and =0.075	and =0.000	and =0.075	and =0.004	and =0.063
			If=0.000	If=0.450	If=0.000	If=0.514	If=0.022	If=0.484

5. Conclusions industrial implications

Concerning the proposed hypotheses, we conclude the following:

1. TPM is a precursor of JIT since the changing intensity between both variables is 0.298.
2. TPM is a precursor of OEE since the changing intensity between both variables is 0.645.
3. TPM is a precursor of ES since the changing intensity between both variables is 0.345.
4. OEE is a precursor of JIT since the changing intensity between both variables is 0.506.
5. OEE is a precursor of ES since the changing intensity between the two variables is 0.295.
6. JIT is a precursor of ES since the changing intensity between both variables is 0.199.

Concerning the sensitivity analysis, it is concluded that:

1. TPM+ always guaranteed to have OEE+, JIT+, ES+ with probabilities of 0.606, 0.576, 0.485, respectively. It is also weakly associated with OEE-, JIT- ES-.
2. TPM- is a risk, as it can generate OEE-, JIT- ES- with probabilities of 0.575, 0.500, 0.450, respectively. It is also weakly associated with OEE+, JIT+, OEE+.
3. OEE+ facilitates the occurrence of JIT+ ES+ with probabilities of 0.533 0.422; furthermore, it is weakly associated with JIT- ES-.
4. OEE- is a risk, as it facilitates the occurrence of JIT- ES- with probabilities of 0.600 0.514. In addition, it is not associated with JIT+ ES+.
5. JIT+ facilitates the occurrence of ES+ with a probability of 0.378 is not associated with ES-.
6. JIT- is a risk since it facilitates ES- with a probability of 0.484 is not associated with ES+.

For discuss the industrial implications, in the following paragraphs, high levels in a variable are represented by the "+" sign low levels by the "-" sign. Thus, for example, TPM+ favors OEE+ with a probability of 0.606; however, if TPM- occurs, then there is a 0.575 probability of obtaining OEE-, hence the importance of this first variable to ensure the material flow through the production system. Moreover, managers can be assured that investments in TPM were profitable since TPM+ is not associated with OEE- graphics in Table 4 indicates almost an increasing linear relationship.

Similarly, TPM+ guarantees JIT+ with a probability of 0.576 is only 0.030 associated with JIT-; that is, TPM facilitates the materials flow in the production system because machines are always available. However, TPM- can generate JIT- with a probability of 0.500 is only weakly associated with JIT+ indicating that stoppages due to machine down makes difficult to have a success on time delivery. However, the best contribution of TPM+ is observed in ES+, which it favors with a probability of 0.485, TPM+ is not associated with ES-, indicating that it always offers some economic benefit for managers. However, having TPM- can also generate ES- with a probability of 0.450, denoting its importance managers must avoid it.

It is also observed that OEE+ can generate JIT+ with a probability of 0.533 that it is weakly associated with JIT- with a probability of 0.022, a very low value. It is also observed that OEE- is not associated with JIT+ since the probability is zero, but it can generate JIT- with a probability of 0.600, a very high value. OEE+ is also a pillar of ES+ since it favors it with a probability of 0.422 is not associated with OEE- since the probability is null; that is, investments made to increase machine availability levels are always reflected in economic benefits. However, OEE- is a risk for ES- since it favors it with a probability of 0.514.
Finally, JIT+ favors ES+ with a probability of 0.378 has a low association with OEE-, as the probability is 0.022. Similarly, JIT- is not associated with ES+ since the probability is zero, but it does represent a risk for ES- since it favors it with a probability of 0.484.

References

Agyabeng-Mensah, Y., Afum, E., Agnikpe, C., Cai, J., Ahenkorah, E., and Dacosta, E. Exploring the mediating influences of total quality management just in time between green supply chain practices performance. *Journal of Manufacturing Technology Management,*vol. 32, no. 1, pp. 156-175, 2021.

Ahuja, I. P. S. , Total Productive Maintenance. In M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, and D. Ait-Kadi (Eds.), *Handbook of Maintenance Management Engineering* (pp. 417-459). London: Springer London. 2009.

Ahuja, I. P. S., and Khamba, J. S. Total productive maintenance: literature review directions. *International Journal of Quality and Reliability Management,*vol. 25, no. 7, pp. 709-756, 2008.

Al-Najjar, B., Hansson, M. O., and Sunnegårdh, P. Benchmarking of maintenance performance: a case study in two manufacturers of furniture. *IMA Journal of Management Mathematics,*vol. 15, no. 3, pp. 253-270, 2004.

Alcaraz, J. L. G., Maldonado, A. A., Iniesta, A. A., Robles, G. C., and Hernández, G. A. A systematic review/survey for JIT implementation: Mexican maquiladoras as case study. *Computers in Industry,*vol. 65, no. 4, pp. 761-773, 2014.

Alseiari, A. Y., Farrell, P., and Osman, Y., Technical Operational Barriers that Affect the Successful Total Productive Maintenance (TPM) Implementation: Case Studies of Abu Dhabi Power Industry. In*: Vol. 166. 32nd International Congress Exhibition on Condition Monitoring Diagnostic Engineering Management, COMADEM 2019* (pp. 1331-1344): Springer Science Business Media DeutschlGmbH. 2020.

Arya, P., Jaiswal, M. P., and Srivastava, M. K. Modelling environmental economic sustainability of logistics. *Asia-Pacific Journal of Business Administration,*vol. 12, no. 1, pp. 73-94, 2019.

Bakri, A. H., Rahim, A. R. A., Yusof, N. M., and Ahmad, R. Boosting Lean Production via TPM. *Procedia - Social Behavioral Sciences,*vol. 65, no., pp. 485-491, 2012.

Bookbinder, J. H., and Ülkü, M. A., Freight Transport Logistics in JIT Systems. In R. Vickerman (Ed.), *International Encyclopedia of Transportation* (pp. 107-112). Oxford: Elsevier. 2021.

Chand, G., and Shirvani, B. Implementation of TPM in cellular manufacture. *Journal of Materials Processing Technology,*vol. 103, no. 1, pp. 149-154, 2000.

Chichilnisky, G. What is sustainability? *nternational Journal of Sustainable Economy,*vol. 3, no. 2, pp. 16, 2011.

Díaz-Reza, J., García-Alcaraz, J., Avelar-Sosa, L., Mendoza-Fong, J., Sáenz Diez-Muro, J., and Blanco-Fernández, J. The Role of Managerial Commitment TPM Implementation Strategies in Productivity Benefits. *Applied Sciences,*vol. 8, no. 7, pp. 1153, 2018.

Esmaeel, R. I., Zakuan, N., Jamal, N. M., and Taherdoost, H. Fit manufacturing; integrated model of manufacturing strategies. *Procedia Manufacturing,*vol. 22, no., pp. 975-981, 2018a.

Esmaeel, R. I., Zakuan, N., Jamal, N. M., and Taherdoost, H. Understanding of business performance from the perspective of manufacturing strategies: fit manufacturing overall equipment effectiveness. *Procedia Manufacturing,*vol. 22, no., pp. 998-1006, 2018b.

Eti, M. C., Ogaji, S., and Probert, S. Implementing total productive maintenance in Nigerian manufacturing industries. *Applied energy,*vol. 79, no. 4, pp. 385-401, 2004.

Fullerton, R. R., Kennedy, F. A., and Widener, S. K. Lean manufacturing firm performance: The incremental contribution of lean management accounting practices. *Journal of Operations Management,*vol. 32, no. 7-8, pp. 414-428, 2014.

García-Alcaraz, J. L., Díaz Reza, J. R., Sánchez Ramírez, C., Limón Romero, J., Jiménez Macías, E., Lardies, C. J., and Rodríguez Medina, M. A. Lean manufacturing tools applied to material flow their impact on economic sustainability. *Sustainability (Switzerland),*vol. 13, no. 19, pp., 2021.

García-Alcaraz, J. L., Prieto-Luevano, D. J., Maldonado-Macías, A. A., Blanco-Fernández, J., Jiménez-Macías, E., and Moreno-Jiménez, J. M. Structural equation modeling to identify the human resource value in the JIT implementation: case maquiladora sector. *International Journal of Advanced Manufacturing Technology,*vol. 77, no. 5-8, pp. 1483-1497, 2015.

Garza-Reyes, J. A. From measuring overall equipment effectiveness (OEE) to overall resource effectiveness (ORE). *Journal of Quality in Maintenance Engineering,*vol. no., pp., 2015.

Heng, Z., Aiping, L., Liyun, X., and Moroni, G. (2019). *Automatic estimate of OEE considering uncertainty.* Paper presented at the 52nd CIRP Conference on Manufacturing Systems, CMS 2019.

INDEX., *Monthly information statistics - Information regarding employment* Retrieved from CIudad Juárez, Mexico: .

INDEX., *Montly information statistics - Information regrading companies*. Retrieved from Ciudad Juárez, Mexico, 2022b.

Jahangir, N., Hasin, A. A., and Bashar, A. Linkage between TPM, people management organizational performance. *Journal of Quality in Maintenance Engineering,* vol. ahead-of-print, no. ahead-of-print, pp., 2020.
Jeong, K. Y., and Phillips, D. T. Operational efficiency effectiveness measurement. *International Journal of Operations and Production Management,* vol. no., pp., 2001.
Jimenez, G., Santos, G., Sá, J. C., Ricardo, S., Pulido, J., Pizarro, A., and Hernández, H. Improvement of Productivity Quality in the Value Chain through Lean Manufacturing – a case study. *Procedia Manufacturing,* vol. 41, no., pp. 882-889, 2019.
Kim, S. C., and Shin, K. S. Negotiation Model for Optimal Replenishment Planning Considering Defects under the VMI JIT Environment. *The Asian Journal of Shipping Logistics,* vol. 35, no. 3, pp. 147-153, 2019.
King, A. A., and Lenox, M. J. Lean green? An empirical examination of the relationship between lean production environmental performance. *Production operations management,* vol. 10, no. 3, pp. 244-256, 2001.
Kumar, J., Kumar Soni, V., and Agnihotri, G. Impact of TPM implementation on Indian manufacturing industry. *International Journal of Productivity Performance Management,* vol. 63, no. 1, pp. 44-56, 2014.
Longoni, A., and Cagliano, R. Cross-functional executive involvement worker involvement in lean manufacturing sustainability alignment. *International Journal of Operations and Production Management,* vol. 35, no. 9, pp. 1332-1358, 2015.
Melesse, W., and Ajit, P. Total productive maintenance: A case study in manufacturing industry. *Global Journal of researches in engineering Industrial engineering,* vol. 12, no. 1, pp. 2, 2012.
Mohd Ghazali Maarof, F. M. A Review of Contributing Factors Challenges in Implementing Kaizen in Small Medium Enterprises. *Procedia Economics Finance,* vol. no., pp., 2016.
Morales-García, A. S., Díaz-Reza, J. R., and García-Alcaraz, J. L., Effect of TPM OEE on the Social Performance of Companies. In J. A. Zapata-Cortes, G. Alor-Hernández, C. Sánchez-Ramírez, and J. L. García-Alcaraz (Eds.), *New Perspectives on Enterprise Decision-Making Applying Artificial Intelligence Techniques* (pp. 119-141). Cham: Springer International Publishing. 2021.
Nakajima, S. Introduction to TPM: total productive maintenance.(Translation). *Productivity Press, Inc., 1988,* vol. no., pp. 129, 1988.
Narusawa, T., and Shook, J. *Kaizen express: Fundamentals for your lean journey*: Lean Enterprise Institute, 2009.
Pinto, G., Silva, F. J. G., Baptista, A., Fernandes, N. O., Casais, R., and Carvalho, C. TPM implementation maintenance strategic plan – a case study. *Procedia Manufacturing,* vol. 51, no., pp. 1423-1430, 2020.
Ribeiro, P., Sá, J. C., Ferreira, L. P., Silva, F. J. G., Pereira, M. T., and Santos, G. The Impact of the Application of Lean Tools for Improvement of Process in a Plastic Company: a case study. *Procedia Manufacturing,* vol. 38, no., pp. 765-775, 2019.
Sahoo, S. Assessment of TPM TQM practices on business performance: a multi-sector analysis. *Journal of Quality in Maintenance Engineering,* vol. 25, no. 3, pp. 412-434, 2019.
Schippers, W. A. An integrated approach to process control. *International journal of production economics,* vol. 69, no. 1, pp. 93-105, 2001.
Seth, D., and Tripathi, D. A critical study of TQM TPM approaches on business performance of Indian manufacturing industry. *Total Quality Management and Business Excellence,* vol. 17, no. 7, pp. 811-824, 2006.
Shen, C.-C. Discussion on key successful factors of TPM in enterprises. *Journal of Applied Research Technology,* vol. 13, no. 3, pp. 425-427, 2015.
Singh, R., Gohil, A. M., Shah, D. B., and Desai, S. Total Productive Maintenance (TPM) Implementation in a Machine Shop: A Case Study. *Procedia Engineering,* vol. 51, no., pp. 592-599, 2013.
Suryaprakash, M., Gomathi Prabha, M., Yuvaraja, M., and Rishi Revanth, R. V. Improvement of overall equipment effectiveness of machining centre using tpm. *Materials Today: Proceedings,* vol. no., pp., 2020.
Thomopoulos, N. T. (2016). Just-in-Time. In N. T. Thomopoulos (Ed.), *Elements of Manufacturing, Distribution Logistics: Quantitative Methods for Planning Control* (pp. 149-164). Cham: Springer International Publishing.

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