33rd European Modeling & Simulation Symposium
18th International Multidisciplinary Modeling & Simulation Multiconference

ISSN 2724-0029 ISBN 978-88-85741-57-7 © 2021 The Authors.
doi: 10.46354/i3m.2021.emss.049

Lean manufacturing tools for support production process and their impact on economic sustainability

Jorge Luis García- Alcaraz [1,2,*], Adrián Salvador Morales García[1], José Roberto Díaz Reza[2] , Silvia Paola Audeves Rubio[1], Emilio Jiménez Macias[3], Manuel Arnoldo Rodríguez Medina[2]

[1] Department of Industrial Engineering and Manufacturing, Autonomous University of Ciudad Juarez, Av. del Charro 450 Norte, Col. Partido Romero, Ciudad Juarez 32310, Chihuahua, México.
[2] Department of Industrial Engineering, Tecnologico Nacional de México/I.T. Ciudad Juárez. Av. Tecnológico 1340, Fuentes del Valle, 32500, Ciudad Juárez, Chihuahua, México.
[3] Department of Electric Engineering, University of La Rioja. Edificio Departamental - C/San José de Calasanz 31, Logroño 26004, La Rioja, Spain.

[*]Corresponding author. E-mail address: jorge.garcia@uacj.mx

Abstract

Industry uses lean tools for improving the production processes and avoids mistakes. This paper presents a structural equation model that integrates three lean manufacturing tools used as supporting: Visual Management, Poka-Yoke, and Andon as independent variables and Economic Sustainability as a dependent variable. The main goal is to measure the direct effect of supporting tools on Economic Sustainability. Variables are related using six hypotheses, and the model is validated with information from 238 responses to a survey applied to the Mexican maquiladora industry, where Visual Management, Poka-Yoke, and Andon are widely used. The partial least squares technique is used to find the relationship among variables analyzed. Findings indicate that all six hypotheses are statistically significant; for example, Visual Management directly and positively affects Andon, Poka-Yoke, and Economic sustainability. Also, Andon has a direct effect on Poka-Yoke and Economic Sustainability, and finally, Poka-Yoke has a direct effect on Economic Sustainability

Keywords: Visual Management; Andon; Poka-Yoke; Economic Sustainability.

1. Introduction

The industrialization of a country's production systems is directly related to its gross domestic product (Hernández-Ramírez, del Castillo-Mussot, & Hernández-Casildo, 2021). However, when countries do not have an adequate level of technification, they receive companies from other countries to strengthen that sector, increase the labor force and acquire taxes.

Mexico has been characterized for receiving world-class foreign companies in its territory, which are called maquiladoras. These companies have their headquarters in other countries and carry out manufacturing operations in Mexico, given the low regional labor costs and proximity to the United States of America and Canada. These companies take advantage of preferential tariffs between both countries due to free trade agreements (J. L. García-Alcaraz et al., 2020).

There are currently 5,138 maquiladora companies in Mexico, of which 498 are located in the state of Chihuahua and 326 in Ciudad Juárez, this being the main sector in the latter region. These companies generate 2,689,209 direct jobs at the national level, 477,480 at the state level in Chihuahua, and 316,619 in Ciudad Juárez, which indicates the social importance of this sector (IMMEX, 2021).

With maquiladoras, also comes technologies and methodologies applied to production systems. One of the most common is Lean manufacturing (LM). LM is defined as a set of tools used in a production system focused on identifying, minimizing, or eliminating waste and reducing costs.

Many studies report the relationship between LM and the benefits offered, focusing on operational and sustainability aspects. For example, Tretyakova, Vladika, Tselyutina, Vlasova, and Timokhina (2020) analyze the effect of LM on supply chains and companies' plans and programs' economic viability. Miehe et al. (2016) y Kalyar, Shafique, and Abid (2019) combine LM with environmental aspects to achieve manufacturing cost optimization and minimize the institutional pressures they develop.

Specifically, the role of LM and its impact on economic aspects is not new and easy to quantify, mainly due to the accounting practices. However, techniques have evolved. Shashi, Centobelli, Cerchione, and Singh (2019) report a structural equation model (SEM) to measure the impact of leanness and innovativeness on economic and environmental performance in Indian firms.

Other studies have analyzed the impact of specific LM Tools (LMT) on economic benefits; Metternich, Bechtloff, and Seifermann (2013) examine the effects of cellular manufacturing on firms' economic efficiency in Europe. Chaabane, Dellagi, Trabelsi, and Schutz (2020) analyze Total Productive Maintenance; Ahmad Musbah Albuhisi and Ayman Bahjat Abdallah (2018) report the case of Total Quality Management (TQM).

However, the above LMTs are the traditional ones applied to a production system. Little is known about using other tools, such as *Visual Management*, *Poka-Yoke*, and Andon, which are applied to support the operator, issue signals to the production lines, and facilitate communication. For example, Tezel and Aziz (2017) analyze the benefits offered by *Visual Management* in the construction sector, and Siaudzionis Filho, Albertin, de Lima, Pontes, and Moraes (2018) report its application in an aircraft assembly line. However, its relationship with economic benefits is not analyzed, focusing on operational aspects.

For their part, Biotto, Mota, Araújo, Barbosa, and Andrade (2014) study Andon in the construction sector for sound emission associated with safety aspects, while Azrul Azwan Abd, Effendi, Mohd Soufhwee Abd, and Teruaki (2019) analyze Andon in manufacturing production systems, without focusing on economic benefits. Similarly, Abed, Elattar, Gaafar, and Alrowais (2020) examine *Poka-Yoke* to increase production processes' reliability. Pötters, Schmitt, and Leyendecker (2018) analyze that tool to increase the effectiveness of quality methods in a mass-production system. Again, the application of *Poka-Yoke* is not associated with the economic benefits obtained from its application.

The application of LM to the maquiladora industry has also been reported, in some cases focusing on certain specific tools, and in others, it is investigated in general terms. For example, Díaz-Reza et al. (2016) analyze the impact of SMED in the Maquiladora industry and the benefits obtained, where economic benefits were one of them. García, Rivera, Blanco, Jiménez, and Martínez (2014) study the impact of Just in Time (JIT) and its relationship with the performance of companies in that sector, and García, Maldonado, Alvarado, and Rivera (2014) study the benefits obtained from applying kaizen.

However, results from LM tools applications such as *Poka-Yoke*, *Visual Management*, and Andon are little known in the maquiladora industry, even with the economic and social importance. This paper aims to present a structural equation model with these LMT as independent variables and relate them to the companies' *Economic Sustainability*. The main contribution in this research is that there will be statistical evidence to measure the dependence among those LMT and the benefits gained.

It is expected that results obtained here will identify the importance of these LMT in the Economic Sustainability of maquiladora industries and that managers can make decisions to strengthen, promote, and manage their resources based on empirical results from this industrial sector.

This article is structured as follows. After the introduction, section two presents a theoretical justification of the hypotheses established as relationships between variables; The third section focuses on defining the methodology. The fourth section presents the results obtained. The fifth section reports a brief conclusion, limitations, and future work.

2. Literature review and hypotheses

2.1. Visual Management (VM)

VM is an LMT focused on the standardization of a company's processes and policies through different means of communication that are attractive to the eye and easy to understand by production line operators (Makhija, Wickramasinghe, & Tiwari, 2021). The benefits obtained from its application refer to the efficiency and effectiveness of problems and procedures in production systems (Kurdve et al., 2019).

To measure VM's level in a company, it is necessary to determine if the operator has the essential information in a visible way to perform his work, if the information is clear and concise, if panels indicate the procedures to be performed (Fundin & Eriksson, 2018). Also, anyone can know the status of the production system due to the information systems. It is easy to make decisions based on the panels and operating guides (Ellis, 2020).

2.2. Andon (AN)

AN is an LMT that groups a set of practical communication measures to let people know a production system's status quickly and efficiently. AN is associated with identifying anomalies and waste, so it aims to disseminate information and facilitate rapid decision-making and minimize the response time. Some authors such as Reyes, Morales, Aldas, Reyes, and Toasa (2019) consider AN to be part of Jidoka; however, that term can be used when signals are generated in machines.

To measure the level of AN implementation in industry, it is generally inquired whether there is a visual control system installed in the production lines, whether it works properly and all employees understand the signals issued quickly (Murata, 2016), and the time with which the departments involved attend to the identified problems, and autonomy of the operator to give an alert or signal (Everett & Sohal, 1991).

For example, in industrial practice, if an operator does not have enough material to maintain the continuous flow, he must order more when there is a minimum inventory, then he can request it through a signal. If the operator knows the technical specifications of the products because he has identified them in some card, then a sign can be used when he sees some deviation (Steenkamp, Hagedorn-Hansen, & Oosthuizen, 2017). Also, if the machine's technical specifications become out of calibration, a signal can be used (Schultz, 2017). Because of the above, the following hypothesis is proposed:

H_1. *Visual Management* has a direct and positive effect on *Andon* in the maquiladora industry.

2.3. Poka-Yoke (PY)

PY is an LMT that refers to devices or mechanisms that prevent human errors that later become quality defects in the product. The central idea is to identify the mistakes, stop them in the production process, and prevent defective products from reaching the customer, minimizing costs associated with guarantees and time loss (Lazarevic, Mandic, Sremcev, Vukelic, & Debevec, 2019).

To know the PY implementation level in the industry, it is generally asked whether the operators are concerned about making a mistake in their activities, whether the machinery is capable of identifying parts of acceptable quality or not (Vinod, Devadasan, Sunil, Thilak, & Murugesh, 2017). Also, whether the machine has built-in error avoidance devices, whether there is assurance that the products meet customer specifications, and whether there are any production order returns due to defects (Consul, 2015).

This lack of concern for making mistakes may be because the operators have read the operating manuals and know their activities according to the process information in panels, signs, and announcements. If they have any doubts about anything, they can consult the operating guides clearly and concisely (Lazarevic et al., 2019). Also, since he knows the operation he performs, the operator can suggest implementing devices that facilitate his work and help avoid errors and accidents (Baseer, Reddy, & Bindu, 2017). Therefore, the following hypothesis is proposed:

H_2. *Visual Management* has a direct and positive effect on *Poka-Yoke* in the maquiladora industry.

However, these devices that help prevent errors may arise in response to a visual monitoring system that indicates that certain operations are being performed incorrectly or necessary to ensure the workers' safety. Also, since he knows the function he performs, the operator can suggest implementing devices that facilitate his work and help avoid errors and accidents (Baseer et al., 2017). Automated instruments can also be integrated into machines because they perform critical activities and require attention in the shortest possible time (Wijaya, Hariyadi, Debora, & Supriadi, 2020). Therefore, the following hypothesis is proposed:

H_3. *Andon* has a direct and positive effect on *Poka-Yoke* in the maquiladora industry.

2.4. Economic Sustainability (ES)

Companies apply LMT hoping to obtain a benefit, and one of them is economic. *Economic Sustainability* is understood as implementing profitable strategies and practices that improve the rational use of resources while maximizing the companies' financial benefits or services (Lehner & Harrer, 2019).

To measure ES in the industry, reducing production costs is calculated (Hami, Muhamad, & Ebrahim, 2015), new product design, and energy consumed (Zhang, Ao, Cai, Jiang, & Zhang, 2019). Also, for inventory management, rejected production orders, raw materials entering the production process, and the treatment of wastes generated (Taucean, Miclea, Ivascu, & Negrut, 2021).

The ES can be due to several factors. One of them is the mistakes rate made by operators who do not know how to execute the tasks and do not know where to consult it since there are no guides or messages on the panels of the machines they operate (Söderlund & Hansson, 2021). All these can translate into economic losses due to rejection of production orders with defects (Paroutis & Knight, 2019). Therefore, it is concluded that putting advertisements indicating how to operate the machines, operation guides, and process maps help to avoid errors that translate into costs, and then the following hypothesis is proposed:

H_4. *Visual Management* has a direct and positive effect on *Economic Sustainability* in the maquiladora industry.

Another ES source can be the savings from the rapid response to machine breakdowns due to effective communication or signaling of the malfunction (Murata, 2016), use of signals that indicate a lack of materials for activity and that the production line is about to be stopped as a result (Taleizadeh, Soleymanfar, & Govindan, 2018) or a signal indicating that a machine is not processing material, is on and wasting power (Jiang, Lyu, Ye, & Zhou, 2020). Therefore, the following hypothesis is proposed:

H_5. *Andon* has a direct and positive effect on *Economic Sustainability* in the maquiladora industry.

Finally, suppose the presence of devices into machines avoids the generation of errors in the production lines. In that case, this means that there are savings for reprocessing to recover part of the raw material and waste (Sundaramali, Abinav Shankar, & Manoj Kummar, 2018). Also, it prevents defective products from arriving at the customer and becoming rejects, and it prevents warranties and transportation costs from becoming valid (Lazarevic et al., 2019). Also, if these devices prevent accidents, it saves on insurance payments, hospitalization costs, etc. (Ahmad, Rashid, Wong, & Iqbal, 2017), among others; therefore, the following hypothesis is proposed:

H_6. *Poka-Yoke* has a direct and positive effect on *Economic Sustainability* in the maquiladora industry.

Figure 1 illustrates the hypotheses graphically.

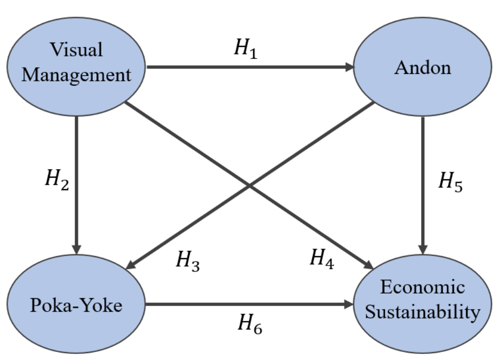

Figure 1. Proposed Model

3. Methodology

Methodology in Figure 2 is used to achieve the main goal:

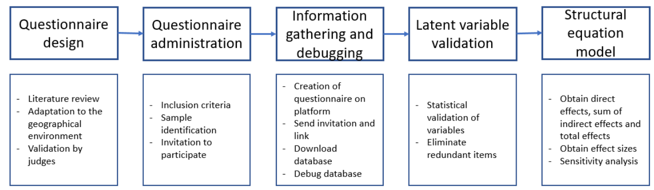

Figure 2. Methodology

3.1. Questionnaire design

To collect the information to evaluate the model, a questionnaire is designed to be applied in the industrial sector of MI. First, a literature review is carried out in Scopus, Research Gate, ScienceDirect, Springer, Emerald Insight to identify the items that indicate the level of implementation of the LMT analyzed (Jorge Luis García-Alcaraz, 2020).

A first questionnaire is designed based on the literature review, which is composed of three sections. The first one seeks to obtain the respondent's demographic information, the second analyzes the three LMT, and the third explores *Economic Sustainability*. Then, a group of experts from industry and academics carries out a judge's validation, and after two rounds, the final questionnaire is obtained.

3.2. Questionnaire administration

The questionnaire is applied to persons involved in the LMT implementation to ensure they know the topics contained in the quaestionnaire, such as managers, engineers, supervisors, and technicians in the maquiladora industry in Ciudad Juarez. According to J. L. García-Alcaraz, Maldonado-Macías, Alor-Hernández, and Sánchez-Ramírez (2017), Ciudad Juárez region has many companies with a good lean manufacturing philosophy implementation plan, which increases the probability of obtaining accurate and valuable information.

The questionnaire is designed on an electronic platform, given the pandemic restrictions by COVID-19. An e-mail with a link to the questionnaire is sent to all potential respondents. If, after three consecutive e-mails, there is no response from the potential respondent, that case is omitted.

3.3. Information gathering and debugging

The questionnaire is applied from September 15 to December 15, 2020, and a database in Excel format is downloaded from the electronic platform. Subsequently, SPSS v.24 software is used to clean the information, where the standard deviation of each case is obtained to identify uncommitted respondents, which are eliminated. Then, missing values are determined in each case and item. If the percentage is greater than 10%, then the case is not integrated into the analysis, but it is replaced by each item's median if it is less. Finally, extreme values are identified by standardizing each item, and if the absolute value is greater than 4, it is replaced with the median.

3.4. Latent variable validation

The variables are validated according to indices proposed by Kock (2017), which are illustrated in Table 1.

Table 1. Validation indices

Indices	Measurement	Suggested value
R^2	Predictive parametric validation	≥ 0.02
Adj. R^2		≥ 0.02
Cronbach´s alpha	Internal consistency	≥ 0.70
Composite reliability		≥ 0.70
Average variance extracted (AVE)	Discriminant validity	≥ 0.50
Full colli. VIF	Collinearity	≤ 3.30
Q^2	Non-parametric predictive validation	Similar to R^2

3.5. Structural equation model

Structural equation modeling (SEM) is used to evaluate the hypotheses; precisely, the partial least squares (PLS) technique integrated into WarpPLS v.7® software (Teo, Tsai, & Yang, 2013), recommended when normality is absent in data, or they are in an ordinal scale (Kock, 2017).

A confidence level of 95% was established, so the p-value must be less than 0.05 for the hypotheses to be statistically significant (Kock, 2016). Before the interpretation of the model, an analysis of its quality and efficiency indices is carried out. The indices are shown in Table 2 (Kock, 2017).

Table 2 Model fit and quality indices

Index	**Measurement**	**Validation**
Average path coefficent (APC)	Average path coefficient	P < 0.05
average R2 (ARS)	Predictive validity	P < 0.05
Averagae adjusted R2 (AARS)	Predictive validity	P < 0.05
Average block VIF (AVIF)	Multicollinearity	< 3.30
Average full collinearity VIF (AFVIF)	Multicollinearity	< 3.30
Tenenhaus GoF (GoF)	The explanatory power of the model	> 0.36

3.5.1. Direct effects and validation of hypotheses

To validate the established hypotheses, direct effects are used. A standardized value β was obtained as the intensity of change between the variables. A p-value is associated with measuring the statistical significance of the same (Westland, 2019). The hypotheses' evaluation is carried out at a 95% confidence level, so the null hypothesis H_0: $\beta = 0$ versus the alternative hypothesis H_1: $\beta \neq 0$ is tested. If it is proved that that $\beta \neq 0$, then it is concluded that there is a relationship between the variables.

3.5.2. Sum of indirect and total effects

Indirect effects occur through third variables, which are called moderators. They use two segments. There can be several for the same relationship and validated with 95% confidence; they are quantified with a standardized value and an associated p-value to determine their statistical significance. Finally, the sum of direct and indirect effects are called total effects and are validated in the same way.

3.5.3. Sensitivity analysis

Finally, a sensitivity analysis is performed for the relationships established as hypotheses since the values of the variables are standardized and allows obtaining probabilities of occurrence at low $P(Z>-1)$ and high $P(Z>1)$ implementation levels (Kock, 2017). In this article, three probabilities are reported; that the variables occur in isolation in any scenario, that they occur jointly (represented by &), and that the dependent variable occurs given that the independent variable has occurred (represented by if).

4. Results

4.1. Descriptive analysis of the sample

At the end of the questionnaire application, 238 valid responses were obtained for analysis. Table 3 illustrates the years of experience in the respondents' positions and their industrial sectors. It is observed that the sector with the highest participation in the automotive sector with 88 (36.9%), followed by the logistics sector with 55 (23.1%) and electrical/electronic with 51 (21.43%). It is also observed that 52.5% of the people who answered the questionnaire have more than two years of experience in their position, so it can be concluded that the answers given are very reliable.

Table 3. Industrial sector and years of expirience

	Years of experience					
Industrial sector	0-1	1-2	2-5	5-10	+10	Total
Automotive	22	5	30	16	15	88
Logistics	12	16	13	7	7	55
Electric/Electronic	25	12	5	4	5	51
Medical	1	6	4	2	7	20
Rubber and Plastic	3	1	3	4	1	12
Machining	7	1	1	0	1	10
Aeronautics	0	2	0	0	0	2
Total	70	43	56	33	36	238

4.2. Descriptive analysis for ítems

Table 4 illustrates the descriptive analysis of the items in the variables, where the median and the interquartile range (IR) are shown, which are ordered according to the highest median value. In general terms, it is observed that for VM, the most important thing is to have the necessary information to carry out its work. For AN, the most important thing is that the companies have a visual and quality management system.

Regarding PY, the most important thing is that there are no customer returns due to product failure, although the value is 3.056 and indicates that some companies have this problem. Finally, the most important thing concerning ES is reducing product development costs since the median value is the highest at 3,671.

Table 4. Descriptive analysis for ítems

Item	Median	IR
VM1 - Visible information is available to perform the work.	**3.888**	1.677
VM2 - Information is clear and concise.	3.821	*1.567*
VM3 - The machinery has visual panels indicating the status of the process	3.779	1.773
AN1 - A good quality visual control system is in place	**3.875**	1.781
AN3 - It is easy to notify of an alert	3.842	*1.663*
AN2 - Visual control is used correctly	3.860	1.792
PY2 - Machinery separates good and defective parts	**3.056**	*1.933*
PY1 - There is no concern about making mistakes	3.009	2.135
PY5 - There are customer returns due to product failure	2.898	2.066
PY3- Machinery prevents you from making mistakes	2.642	2.268
ES3 - Reduced product development costs	**3.671**	*1.665*
ES5 - Reduced inventory costs	3.536	1.861
ES7 - Decrease in raw material costs	3.618	1.799
ES6 - Reduced scrap and rework costs	3.558	1.857
ES4 - Reduced energy costs	3.613	1.737

4.3. Latent variable validation

Table 4 illustrates the validation indexes for latent variables. It is concluded according to R^2 and adjusted R^2 values that all variables have sufficient parametric predictive validity. At the same time, Cronbach's alpha and Composite reliability indicate internal consistency, and AVE demonstrates acceptable convergent validity. VIF suggests that the absence of collinearity and Q^2 indicates non-parametric predictive validity, so the variables are integrated into the structural equation model.

Table 5. Latent variable validation

	Visual Management	*Andon*	*Poka -Yoke*	*Economic Sustainability*
R^2		0.374	0.131	0.438
Adj. R^2		0.371	0.124	0.431
Composite Reliability	0.906	0.922	0.848	0.938
Cronbach´s alpha	0.844	0.874	0.759	0.917
AVE	0.763	0.798	0.583	0.75
Full collin. VIF	1.797	1.802	1.146	1.747
Q^2		0.374	0.132	0.441

4.4. Structural equation model

The model is run, and the following model efficiency and quality indexes are obtained; APC=0.303, ARS=0.314, and AARS=0.309 indicating the model's predictive validity since the associated p-values are P<0.001. It is observed that there are no collinearity problems as the VIF and AVIF values are less than 3.3, and there is a good fit of the data to the model, as the GoF>0.36 index.

According to the above values, it is concluded that the model can be interpreted, and Figure 3 shows each of the hypotheses, the β values, and the associated p-value, as well as the R^2 value for the dependent variables. Figure 3 shows that all hypotheses are statistically significant since the P values are less than 0.05. Table 5 illustrates the contribution of each independent variable in explaining the dependent variable through the effect size, where it is observed that AN is the variable that contributes most in explaining ES.

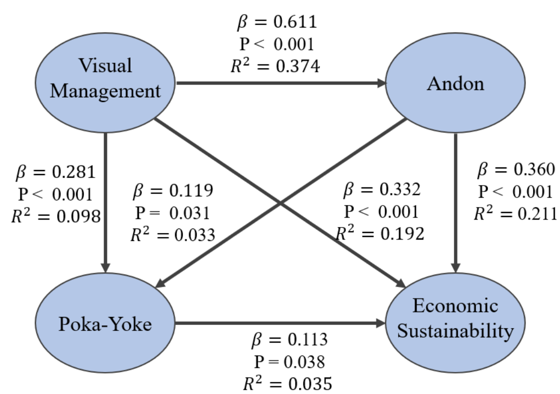

Figure 3. Evaluated model

Table 5. Contribution of R^2 in direct effects

	VM	AN	PY	R^2
AN	0.374			0.374
PY	0.098	0.033		0.131
ES	0.192	0.211	0.035	0.438

4.4.2. Sum of indirect and total effects

Table 6 illustrates the sum of indirect and total effects. It is observed that there are three indirect effects, and all of them are statistically significant, as are the six total effects. The largest total effect is in the relationship between VM→AN with β=0.611 and contributes to explain the variance by 0.374. The second-largest effect is between VM→ES with a β=0.592 and contribution of 0.342 to the variance.

4.4.3 Sensitivity analysis

Table 7 presents the sensitivity analysis for the hypotheses in Figure 1. The probabilities for the high scenarios are indicated by the symbol "+" in each latent variable, and the low scenario is indicated by the symbol "-". Also, the joint probabilities are indicated as "&" and conditional probabilities by "if". For example, the probability of VM+ and PY+ occurring together is 0.054, but the probability of PY+ occurring given that VM has occurred is 0.295.

Table 6. Sum of indirect and total effects

Sum of indirect effects			
	VM	AN	PY
PY	β=0.073 P=0.054 ES=0.025		
ES	β=0.260 P<0.001 ES=0.150	β=0.013 P<0.001 ES=0.008	
Sum of total effects			
AN	β=0.354 P<0.001 ES=0.123	β=0.119 P=0.031 ES=0.033	
PY	β=0.592 P<0.001 ES=0.342	β=0.374 P<0.001 ES=0.219	β=0.113 P=0.038 ES=0.035
ES	β=0.354 P<0.001 ES=0.123	β=0.119 P=0.031 ES=0.033	

Similarly, the probability of PY- occurring given that VM- has happened is 0.357, a high risk for managers and administrators. The other relationships are interpreted similarly.

Tabla 7. Sensitivity analysis

Level		VM+	VM-	AN+	AN-	PY+	PY-
	Prob	0.184	0.176	0.172	0.146	0.176	0.167
AN+	0.172	&=0.067 If=0.364	&=0.008 If=0.048				
AN-	0.146	&=0.017 If=0.091	&=0.084 If=0.476				
PY+	0.176	&=0.054 If=0.295	&=0.004 If=0.024	&=0.059 If=0.341	&=0.008 If=0.057		
PY-	0.167	&=0.017 If=0.091	&=0.063 If=0.357	&=0.029 If=0.171	&=0.042 If=0.286		
ES+	0.151	&=0.075 If=0.409	&=0.004 If=0.024	&=0.079 If=0.463	&=0.000 If=0.000	&=0.050 If=0.286	&=0.008 If=0.050
ES-	0.138	&=0.008 If=0.045	&=0.079 If=0.452	&=0.004 If=0.024	&=0.063 If=0.429	&=0.017 If=0.095	&=0.042 If=0.250

*PY= *Poka-Yoke*; AN = *Andon*; VM = *Visual Management*; ES = *Economic Sustainability*

5. Conclusiones

The following conclusions can be drawn from the structural equation model and the hypotheses.

H_1. There is statistical evidence to state that *Visual Management* has a direct and positive effect on *Andon* in the maquiladora industry since when the first variable increases its standard deviation by one unit, the second increases it by 0.611 units.

H_2. There is statistical evidence to state that *Visual Management* directly and positively affects *Poka-Yoke* in the maquiladora industry. When the first variable increases its standard deviation by one unit, the second increases it by 0.281 units.

H_3. There is statistical evidence to state that *Andon* directly and positively affects *Poka-Yoke* in the maquiladora industry. When the first variable increases its standard deviation by one unit, the second increases it by 0.119 units.

H_4. There is statistical evidence to state that *Visual Management* directly affects *Economic Sustainability* in the maquiladora industry. When the first variable increases its standard deviation by one unit, the second increases it by 0.0.332 units.

H_5. There is statistical evidence to state that *Andon* has a direct and positive effect on *Economic Sustainability* in the maquiladora industry since when the first variable increases its standard deviation by one unit, the second increases by 0.360 units.

H_6. There is statistical evidence to state that *Poka-Yoke* directly and positively affects *Economic Sustainability* in the maquiladora industry, because when the first variable increases its standard deviation by one unit, the second increases by 0.113 units.

Furthermore, from the sensitivity analysis, it is observed that VM+ generates AN+, PY+, and ES+, since the conditional probabilities are 0.364, 0.295, and 0.409, respectively. Furthermore, VM+ has little association with AN-, PY-, and ES-, but if VM- occurs, then AN-, PY-, and ES- are at risk with probabilities of 0.476, 0.357, and 0.452.

Likewise, if VM+ is reached, PY+ and ES+ can occur with a probability of 0.341 and 0.463, also VM+ is not associated with PY- and ES-, as the probabilities are low. However, if AN- occurs, then there is a risk of obtaining PY- and ES- with a probability of 0.286 and 0.429, respectively. Finally, PY+ facilitates obtaining ES+ with a probability of 0.286, but if PY- occurs, then ES- may occur with a probability of 0.250.

References

Cox, D. R. (1972). Regression models and life tables (with Discussion). *J. R. Statist. Soc.* B, 34:187–220.

Fan, J. and Peng, H. (2004). Nonconcave penalized likelihood with a diverging number of parameters. *Ann. Statist.*, 32:928–61.

Heard, N. A., Holmes, C. C., and Stephens, D. A. (2006). A quantitative study of gene regulation involved in the immune response of Anopheline mosquitoes: An application of Bayesian hierarchical clustering of curves. *J. Am. Statist. Assoc.*, 101:18–29.

Abed, A. M., Elattar, S., Gaafar, T. S., & Alrowais, F. (2020). Artificial poka-yoke increases process reliability via a hybrid of the neural network with arima results. *International Journal of Mechanical and Production Engineering Research and Development,* *10*(2), 931-954.

doi:https://doi.org/10.24247/ijmperdapr202092

Ahmad, A. A., Rashid, A. A., Wong, F. R., & Iqbal, M. (2017). Worker safety improvement at paper pleating production line using poka-yoke concept - A case study in automotive industry. *Journal of Mechanical Engineering, SI* 4(5), 183-196. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-85042037135&partnerID=40&md5=b8bcfd41f1ebf403444f495819989079

Ahmad Musbah Albuhisi, a., & Ayman Bahjat Abdallah, a. (2018). The impact of soft TQM on financial performance : The mediating roles of non-financial balanced scorecard perspectives. *International Journal of Quality & Reliability Management*(7), 1360. doi:https://doi.org/10.1108/IJQRM-03-2017-0036

Azrul Azwan Abd, R., Effendi, M., Mohd Soufhwee Abd, R., & Teruaki, I. (2019). Framework of Andon Support System in Lean Cyber-Physical System Production Environment. *The Proceedings of Manufacturing Systems Division Conference*, 404. doi:https://doi.org/10.1299/jsmemsd.2019.404

Baseer, K. K., Reddy, A. R. M., & Bindu, C. S. (2017). FPYM: Development and application of a fuzzy-based Poka-Yoke model for the improvement of software performance. *International Journal of Innovative Computing and Applications*, 8(2), 65-80. doi:https://doi.org/10.1504/IJICA.2017.084889

Biotto, C., Mota, B., Araújo, L., Barbosa, G., & Andrade, F. (2014). *Adapted use of andon in a horizontal residential construction project.* Paper presented at the 22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production, IGLC 2014.

Chaabane, K., Dellagi, S., Trabelsi, W., & Schutz, J. (2020). Analytical evaluation of TPM performance based on an economic criterion. *Journal of Quality in Maintenance Engineering, ahead-of-print*(ahead-of-print). doi:https://doi.org/10.1108/JQME-08-2019-0085

Consul, J. T. (2015). The application of the Poka-Yoke method in the manufacturing of steel structures. *Producao,* 25(3), 678-690. doi:https://doi.org/10.1590/0103-6513.084012

Díaz-Reza, J. R., García-Alcaraz, J. L., Martínez-Loya, V., Blanco-Fernández, J., Jiménez-Macías, E., & Avelar-Sosa, L. (2016). The effect of SMED on benefits gained in maquiladora industry. *Sustainability (Switzerland),* 8(12). doi:https://doi.org/10.3390/su8121237

Ellis, G. (2020). Chapter 19 - Workflow—Visual management for initiatives and projects. In G. Ellis (Ed.), *Improve* (pp. 345-366). Boston: Butterworth-Heinemann.

Everett, R. J., & Sohal, A. S. (1991). Individual Involvement and Intervention in Quality Improvement Programmes: Using the Andon System. *International Journal of Quality & Reliability Management,* 8(2). doi:https://doi.org/10.1108/EUM0000000001635

Fundin, A., & Eriksson, Y. (2018). Visual management for a dynamic strategic change. *Journal of Organizational Change Management, 31*(3), 712-727. doi:https://doi.org/10.1108/JOCM-05-2016-0103

García-Alcaraz, J. L. (2020). Validación De Cuestionario Para Conocer El Nivel De Implementación De Lean Manufacturing. *Instituto de Ingeniería y Tecnología.*

García-Alcaraz, J. L., Maldonado-Macías, A. A., Alor-Hernández, G., & Sánchez-Ramírez, C. (2017). The impact of information and communication technologies (ICT) on agility, operating, and economical performance of supply chain. *Advances in Production Engineering And Management,* 12(1), 29-40. doi:10.14743/apem2017.1.237

García-Alcaraz, J. L., Martínez-Loya, V., Díaz-Reza, J. R., Blanco-Fernández, J., Jiménez-Macías, E., & López, A. J. G. (2020). Effect of ICT integration on SC flexibility, agility and company' performance: the Mexican maquiladora experience. *Wireless Networks,* 26(7), 4805-4818. doi:https://doi.org/10.1007/s11276-019-02068-6

García, J. L., Maldonado, A. A., Alvarado, A., & Rivera, D. G. (2014). Human critical success factors for kaizen and its impacts in industrial performance. *International Journal of Advanced Manufacturing Technology,* 70(9-12), 2187-2198. doi:10.1007/s00170-013-5445-4

García, J. L., Rivera, L., Blanco, J., Jiménez, E., & Martínez, E. (2014). Structural equations modelling for relational analysis of jit performance in maquiladora sector. *International Journal of Production Research,* 52(17), 4931-4949. doi:10.1080/00207543.2014.885143

Hami, N., Muhamad, M. R., & Ebrahim, Z. (2015). The Impact of Sustainable Manufacturing Practices and Innovation Performance on Economic Sustainability. *Procedia CIRP,* 26, 190-195.

doi:https://doi.org/10.1016/j.procir.2014.07.167

Hernández-Ramírez, E., del Castillo-Mussot, M., & Hernández-Casildo, J. (2021). World per capita gross domestic product measured nominally and across countries with purchasing power parity: Stretched exponential or Boltzmann–Gibbs distribution? *Physica A: Statistical Mechanics and its Applications, 568*, 125690. doi:https://doi.org/10.1016/j.physa.2020.125690

IMMEX. (2021). *Monthly statistical information - Employment* Retrieved from Ciudad Juárez, CHIH, Mexico:

Jiang, Z., Lyu, P., Ye, L., & Zhou, Y. w. (2020). Green innovation transformation, economic sustainability and energy consumption during China's new normal stage. *Journal of Cleaner Production, 273*, 123044. doi:https://doi.org/10.1016/j.jclepro.2020.123044

Kalyar, M. N., Shafique, I., & Abid, A. (2019). Role of lean manufacturing and environmental management practices in eliciting environmental and financial performance: the contingent effect of institutional pressures. *Environmental Science and Pollution Research, 26*(24), 24967-24978. doi:https://doi.org/10.1007/s11356-019-05729-3

Kock, N. (2016). Hypothesis Testing with Confidence Intervals and P Values in PLS-SEM. *Int. J. e-Collab., 12*(3), 1-6. doi:10.4018/IJeC.2016070101

Kock, N. (2017). WarpPLS user manual: Version 6.0. *ScriptWarp Systems: Laredo, TX, USA.*

Kurdve, M., Harlin, U., Hallin, M., Söderlund, C., Berglund, M., Florin, U., & Landström, A. (2019). Designing visual management in manufacturing from a user perspective. *Procedia CIRP, 84*, 886-891. doi:https://doi.org/10.1016/j.procir.2019.04.310

Lazarevic, M., Mandic, J., Sremcev, N., Vukelic, D., & Debevec, M. (2019). A systematic literature review of poka-yoke and novel approach to theoretical aspects. *Strojniski Vestnik/Journal of Mechanical Engineering, 65*(7-8), 454-467. doi:https://doi.org/10.5545/sv-jme.2019.6056

Lehner, O. M., & Harrer, T. (2019). Accounting for economic sustainability: environmental, social and governance perspectives. *Journal of Applied Accounting Research, 20*(4), 365-371. doi:https://doi.org/10.1108/JAAR-06-2019-0096

Makhija, A., Wickramasinghe, C., & Tiwari, M. (2021). 5 - Visual management. In P. Jana & M. Tiwari (Eds.), *Lean Tools in Apparel Manufacturing* (pp. 131-208): Woodhead Publishing.

Metternich, J., Bechtloff, S., & Seifermann, S. (2013). Efficiency and Economic Evaluation of Cellular Manufacturing to Enable Lean Machining. *Procedia CIRP, 7*, 592-597. doi:https://doi.org/10.1016/j.procir.2013.06.038

Miehe, R., Bogdanov, I., Schneider, R., Hirsch, M., Bauernhansl, T., Pawlik, E., & Horbal, R. (2016). The Eco Lean Method – A Combined Approach for Low Cost Economic and Ecologic Optimization in the Manufacturing Industry. *Procedia CIRP, 57*, 613-618. doi:https://doi.org/10.1016/j.procir.2016.11.106

Murata, K. (2016). *On application of ANDON tool as information-sharing System used in construction industry.* Paper presented at the CIE 2016: 46th International Conferences on Computers and Industrial Engineering.

Paroutis, S., & Knight, E. (2019). How Visual Methods Can Enhance Our Understanding of Strategy and Management. In *Standing on the Shoulders of Giants* (Vol. 11, pp. 77-90): Emerald Publishing Limited.

Pötters, P., Schmitt, R., & Leyendecker, B. (2018). Effectivity of quality methods used on the shop floor of a serial production–how important is Poka Yoke? *Total Quality Management and Business Excellence, 29*(9-10), 1200-1212. doi:https://doi.org/10.1080/14783363.2018.1488559

Reyes, J., Morales, L., Aldas, D., Reyes, R., & Toasa, R. (2019). Real time automatic andon alerts for android platforms applied in footwear manufacturing. In *Communications in Computer and Information Science* (Vol. 959, pp. 43-56).

Schultz, A. L. (2017). Integrating lean and visual management in facilities management using design science and action research. *Built Environment Project and Asset Management, 7*(3), 300-312. doi:https://doi.org/10.1108/BEPAM-05-2016-0020

Shashi, Centobelli, P., Cerchione, R., & Singh, R. (2019). The impact of leanness and innovativeness on environmental and financial performance: Insights from Indian SMEs. *International Journal of Production Economics, 212*, 111-124. doi:https://doi.org/10.1016/j.ijpe.2019.02.011

Siaudzionis Filho, F. A. B., Albertin, M. R., de Lima, R. L. M., Pontes, H. L. J., & Moraes, T. d. C. (2018). Application of visual management panel on an airplane assembly station. *International Journal of Productivity and Performance Management, 67*(6), 1045-1062. doi:https://doi.org/10.1108/IJPPM-09-2016-

0189

Söderlund, C., & Hansson, M. (2021). A visual and rhetorical perspective on management control systems. *International Journal of Lean Six Sigma, ahead-of-print*(ahead-of-print). doi:https://doi.org/10.1108/IJLSS-03-2020-0033

Steenkamp, L. P., Hagedorn-Hansen, D., & Oosthuizen, G. A. (2017). Visual Management System to Manage Manufacturing Resources. *Procedia Manufacturing, 8*, 455-462. doi:https://doi.org/10.1016/j.promfg.2017.02.058

Sundaramali, G., Abinav Shankar, S., & Manoj Kummar, M. (2018). Non-conformity recovery and safe disposal by Poka Yoke and hallmarking in a piston unit. *International Journal of Productivity and Quality Management, 24*(4), 460-474. doi:https://doi.org/10.1504/IJPQM.2018.093445

Taleizadeh, A. A., Soleymanfar, V. R., & Govindan, K. (2018). Sustainable economic production quantity models for inventory systems with shortage. *Journal of Cleaner Production, 174*, 1011-1020. doi:https://doi.org/10.1016/j.jclepro.2017.10.222

Taucean, I. M., Miclea, S., Ivascu, L., & Negrut, M. L. (2021) Analysis of interrelationship for lean and sustainability principles and implications. In*: Vol. 1221 AISC. Advances in Intelligent Systems and Computing* (pp. 217-227).

Teo, T., Tsai, L. T., & Yang, C.-C. (2013). Applying Structural Equation Modeling (SEM) in Educational Research. In M. S. Khine (Ed.), *Application of Structural Equation Modeling in Educational Research and Practice* (pp. 3-21). Rotterdam: SensePublishers.

Tezel, A., & Aziz, Z. (2017). Benefits of visual management in construction: cases from the transportation sector in England. *Construction Innovation, 17*(2), 125-157. doi:https://doi.org/10.1108/CI-05-2016-0029

Tretyakova, L. A., Vladika, M. V., Tselyutina, T. V., Vlasova, T. A., & Timokhina, O. A. (2020). Profitable production as a socio-economic based on supply chain management with lean production. *International Journal of Supply Chain Management, 9*(4), 1174-1181.

Vinod, M., Devadasan, S. R., Sunil, D. T., Thilak, V. M. M., & Murugesh, R. (2017). POYSS: A model for integrating Poka-Yoke technique with Six Sigma concept. *International Journal of Productivity and Quality Management, 22*(2), 223-242. doi:https://doi.org/10.1504/IJPQM.2017.10007221

Westland, J. C. (2019). Partial Least Squares Path Analysis. In J. C. Westland (Ed.), *Structural Equation Models: From Paths to Networks* (pp. 17-38). Cham: Springer International Publishing.

Wijaya, S., Hariyadi, S., Debora, F., & Supriadi, G. (2020). Design and implementation of poka-yoke system in stationary spot-welding production line utilizing internet-of-things platform. *Journal of ICT Research and Applications, 14*(1), 34-50. doi:https://doi.org/10.5614/itbj.ict.res.appl.2020.14.1.3

Zhang, X., Ao, X., Cai, W., Jiang, Z., & Zhang, H. (2019). A sustainability evaluation method integrating the energy, economic and environment in remanufacturing systems. *Journal of Cleaner Production, 239*, 118100. doi:https://doi.org/10.1016/j.jclepro.2019.118100