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Human resources - a critical success factor for quality and sustainability in the industry

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Abstract — **Quality (QUA) in industry encompasses several critical success factors (CSF), including human resources (HR), and the production process is of paramount importance; consequently, quantifying their impact and contribution is essential for sustainability. This study presents a structural equation model (SEM) that relates managerial commitment (MAC) as an independent variable, operators (OPE), suppliers (SUP), and lean manufacturing tools (LMT) as mediating variables, and QUA as a sustainable response variable. The variables were interconnected through six hypotheses, each validated using data from 286 responses to a questionnaire administered to the Mexican maquiladora industry. The SEM was validated using the partial least squares (PLS) approach, and a sensitivity analysis was also performed. The findings indicate that MAC has direct and positive effects on OPE, LMT, and SUP, with the former exhibiting the strongest influence. Similarly, OPE, LMT, and SUP directly affect QUA for sustainability, with the latter demonstrating the most significant impact. The study concludes, statistically and empirically demonstrates that human factors (managers, SUP, and OPE) and production systems can ensure product QUA and economic sustainability, thereby reducing defects and customer returns.**

Keywords: **management commitment; Operators; Suppliers; QUA; Sustainability.**

Resumen — **La calidad (QUA) en la industria abarca varios factores críticos de éxito (CSF), incluidos los recursos humanos (RR. HH.), y el proceso de producción es de suma importancia; en consecuencia, cuantificar su impacto y contribución es esencial para la sostenibilidad. Este estudio presenta un modelo de ecuaciones estructurales (SEM) que relaciona el compromiso directivo (MAC) como variable independiente, los operadores (OPE), los proveedores (SUP) y las herramientas de fabricación ajustada (LMT) como variables mediadoras, y la QUA como variable de respuesta sostenible. Las variables se interconectaron a través de seis hipótesis, cada una validada utilizando datos de 286 respuestas a un cuestionario administrado a la industria maquiladora mexicana. El SEM se validó utilizando el enfoque de mínimos cuadrados parciales (PLS), y también se realizó un análisis de sensibilidad. Los resultados indican que MAC tiene efectos directos y positivos en OPE, LMT y SUP, siendo el primero el que ejerce una mayor influencia. Del mismo modo, OPE, LMT y SUP afectan directamente a QUA en cuanto a sostenibilidad, siendo este último el que demuestra el impacto más significativo. El estudio concluye, demostrando estadística y empíricamente, que los factores humanos (directivos, SUP y OPE) y los sistemas de producción pueden garantizar la sostenibilidad económica y de QUA de los productos, reduciendo así los defectos y las devoluciones de los clientes.**

Palabras Clave: **Compromiso de la dirección; Operadores; Proveedores; Calidad; Sostenibilidad.**

I. INTRODUCTION

QUALITY (QUA) is a complex concept that refers to the degree to which a product meets predefined characteristics and satisfies customer needs and expectations; however, human resources (HRs) are responsible for this [1]. This QUA depends on several factors such as the high management commitment (MAC), operators (OPE), and suppliers (SUP) of raw materials, all of which refer to people.

High product QUA enhances organizational competitiveness, sustainability, and customer satisfaction, resulting in increased sales and loyalty. Furthermore, they contribute to the reduction of waste and resource utilization [2]. Human resource departments play a critical role in achieving QUA assurance standards through planning, coordinating, and supervising activities. They have developed and implemented policies that align with daily operations and sustainability objectives. Effective communication with OPE facilitates the conveyance of QUA assurance objectives and sustainable procedures while obtaining feedback on challenges and opportunities [3]. Nevertheless, continuous training is essential for OPE to maintain high-QUA assurance standards, necessitating management-authorized resources.

Managers play a crucial role in implementing QUA best practices in production lines, approving economic improvements and investments, adhering to ISO 9001 standards, and establishing sustainable metrics and continuous monitoring programs to identify defects and reduce costs using lean manufacturing (LM). Research indicates that promoting production process improvements enhances product QUA and increases

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job satisfaction. Furthermore, standardized processes using QUA culture are essential [4].

Another HR with which managers interact outside the company is SUP. These managers are responsible for integrating SUP and their incorporation into the production process, as they possess knowledge of the technical characteristics of the supplied raw materials and can propose improvements to the system and its operations [5]. The extant literature suggests that the effective integration of SUP results in reduced cycle times, optimized inventories, and shared QUA standards, benefiting both customers and manufacturers.

SUP reduce defects in raw materials by offering QUA and participating in manufacturing innovations for sustainable products. They are required to provide technology for new products [6]. Long-term relationships with SUP, characterized by high trust, enable the negotiation of prices and delivery dates, cost reduction, and economic sustainability.

Managers must align OPE, lean manufacturing techniques, and supplier entities to offer QUA and sustainable agreements with human resources, production processes, SUP, production systems, and OPE as critical success factors [7]. However, those who control or manage these entities are managers; thus, MAC is a critical factor upon which many others depend on their decision-making power and access to resources.

Numerous studies have analyzed the critical success factors for QUA. For instance, Fotopoulos and Psomas [8] related the critical factors of Total QUA Management to the organizational and economic performance of companies, and Carmona-Márquez, *et al.* [9] analyzed whether all factors that favor QUA success have the same impact, and determined that human resources excel over others by being the executors of production plans and programs. Bubb [10] asserted that human resources must be reliable and skilled in generating QUA; otherwise, they will make numerous mistakes, resulting in costly defects. Kujawińska, *et al.* [11] indicated that OPE should be motivated by the management to inspect their processes and machines. Fu, *et al.* [12] argue that SUP are also the basis of QUA for manufacturers. Khalili, *et al.* [13] reported that QUA is achieved in the production process with the support of the OPE and SUP. However, these studies analyze human factors and the productive process in isolation as critical success factors of QUA, and do not allow for an integrated analysis linking them. Furthermore, it is not known what occurs if there are low or high levels of implementation for some of these variables, which is limited to speculations without a statistical basis.

This study aims to analyze the human resources involved in generating product QUA (MAC, OPE, and SUP) and the production process and quantify their relationship and impact on the achievement of QUA. It is hypothesized that the independent variable is the MAC associated with managers, who, owing to their decision-making power and access to resources, favor the performance of the OPE, integrate the SUP, and decide which lean manufacturing techniques to integrate into the production process, which are mediating variables that favor product QUA as the dependent variable, a sustainable measurement.

The results of this study will allow managers to have an empirical and statistically validated basis on which to determine the variables that are important to achieve QUA in their products, and thus make better-informed decisions and allocate resources appropriately. To the best of our knowledge, this is the first study to report a probability-based sensitivity analysis to identify the risks of low-level implementation of the latent variables analyzed.

Following this introduction, section two presents a literature review and hypotheses, section three presents the methodology, section four reports the results and discussion, and section five presents the conclusions.

II. LITERATURE REVIEW AND HYPOTHESES

MAC is critical for ensuring QUA, because it directly influences SUP, OPE, and the production process. MAC establishes the foundation for an organization's culture and operating practices, thereby affecting employee motivation, commitment, and sustainability. Literature indicates that managers' strong leadership and commitment to QUA are essential for fostering a productive process that generates QUA. When demonstrated, this instills a sense of purpose and responsibility among employees–a principle of social sustainability.

Achieving QUA standards is not a straightforward process, and OPE' participation in production processes is necessary, with managers responsible for their integration. For instance, involving workers in decision-making enhances their sense of ownership and accountability for QUA outcomes, as they perceive their contributions as valuable and contributory to the product's QUA, subsequently increasing their motivation and morale [14].

Furthermore, MAC with QUA is manifested in the establishment of robust protocols that ensure safety and guide employees in their daily tasks within the production process, emphasizing QUA [15]. Effective QUA management systems in the manufacturing and service industries have been demonstrated to facilitate the organization of operations, define responsibilities, and document processes, which are crucial for maintaining consistent and certifying QUA. Additionally, committed managers consistently allocate the resources necessary to improve production processes, including budgets, personnel, and equipment, to QUA initiatives.

Similarly, MAC ensures the integration of QUA into an organization's strategy. To achieve this goal, managers must select appropriate machines or production methodologies to be implemented in the production system. For example, they are responsible for implementing other LM tools and providing resources such as total productive maintenance (TPM) and quick changeovers (SMED). In conclusion, managers are responsible for continuous improvements in the production process, and those collaborating with OPE can swiftly identify areas of opportunity.

Managers are also responsible for directly liaising with SUP to ensure product QUA [16]. To accomplish this, they must clearly articulate the raw material expectations of SUP, test procedures, and delivery standards, specifying quantities and delivery times. However, they are also responsible for performing tasks that facilitate joint development with SUP, thereby enabling them to improve their processes and maintain a sustainable production line. This typically involves audits, training in the manufacturer's production process, technical assistance, and certification programs, which indicate the level of collaboration.

Consequently, MAC is related to several entities within and outside the company, and the following hypotheses are proposed:

H_1. Management commitment has a direct and positive effect on operators to ensure QUA.

H_2. Management commitment directly and positively affects the Lean manufacturing tools to ensure QUA.

H_3. Management commitment has a direct and positive effect on SUP in ensuring QUA.

However, it is essential to ascertain the direct effects of these variables (SUP, OPE, and LMT) on product QUA in a direct manner. For instance, Febriani, *et al*. [17] determined that OPE significantly influence product QUA through decision-making and adherence to QUA control protocols in production lines. They can prioritize activities and processes that facilitate compliance with time, quantity, and established standards [18]. Furthermore, OPE are the primary identifiers of defects when performing self-inspection, and they require knowledge and empowerment regarding the production process and the machines they operate.

Similarly, SUP are considered another CSF for QUA, as they provide raw materials in the required quantity and time and convey essential information, facilitating production process operations [19]. SUP constitute the foundation on which the QUA of a product is constructed. Therefore, meticulous selection and effective management of SUP must be conducted to ensure that they meet the required technical and sustainable standards. Consequently, close collaboration between the manufacturer and its SUP is necessary for the identification and resolution of QUA-related issues, and to reduce costs due to waste and rejections that affect customer satisfaction and increase expenses. Thus, SUP should be regarded as strategic allies that enable manufacturers to guarantee a reliable and durable product that meets market expectations.

However, SUP and OPE can only generate a QUA through an efficient production process that requires calibrated machines that do not generate waste or rework. In this production process, other LMTs that support QUA are implemented, such as Kaizen, which focuses on continuous improvement and waste reduction; 5S, because a clean and organized workplace identifies QUA problems, reduces errors, and improves delivery times; poka-yoke, which prevents errors by incorporating devices into machines and tools; Kanban as a visual aid to improve the flow of materials and to perform only the required activities; TPM to calibrate machines; and a value stream map (VSM) to compare the system states before and after an intervention [20], among others. Therefore, the following hypotheses are proposed:

H_4. Operators have a direct and positive effect on the QUA of the production process.

H_5. Suppliers have a direct and positive effect on the QUA of the production process.

H_6. Lean manufacturing tools implemented in the production process have a direct and positive effect on the QUA obtained.

The relationships between the variables established as hypotheses are shown in Figure 1.

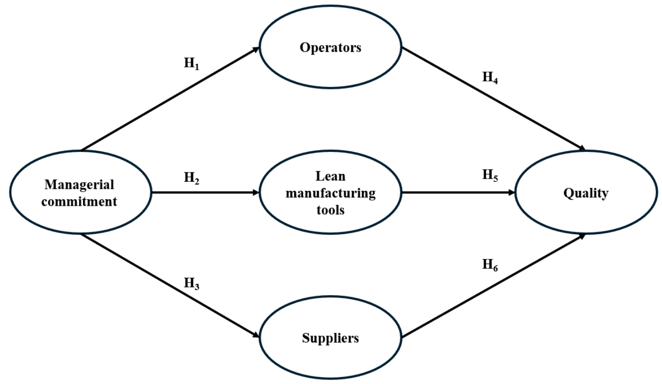

Figure 1. Proposed hypotheses

III. MATERIALS AND METHODS

A. Stage 1. Design of a questionnaire

To validate the hypotheses, data are required from managers, engineers, and individuals associated with the supply chain who oversee OPE in the Mexican Maquiladora industry. The variables in Figure 1 are latent and can be elucidated using other observed variables (items). A comprehensive literature review was conducted to identify previous studies in which these variables were analyzed, facilitating the development of an initial questionnaire. This questionnaire was subsequently validated in a geographical context by a panel of judges who evaluated aspects pertaining to the clarity and precision of the items, their relevance, coherence, and neutrality [21].

The final questionnaire was reviewed and the Institutional Commission on Research Ethics and Bioethics oversaw the project to ensure compliance with the Helsinki Agreement. The questionnaire comprised three sections: the first inquired about demographic aspects; the second investigated the critical success factors of QUA; and the third examined the benefits of QUA. While the first section of the questionnaire was optional, the second and third sections utilized a 5-point Likert scale (1-5) for responses.

B. Stage 2. Application of the questionnaire

The Google Forms platform was utilized to administer an online questionnaire to managers and engineers who had a minimum of one year of experience in their respective positions and had implemented QUA projects, which were required to be concluded to enable the evaluation of the benefits and results. An electronic mail containing a hyperlink to the online questionnaire was sent to potential respondents; however, two additional questions were incorporated. The initial question inquired about respondents' willingness to participate in the research and their agreement with the academic and scientific use of the information. In the event of disagreement, the questionnaire was terminated without further response. The questionnaire was accessible between March 1 and June 1, 2024.

C. Stage 3. Debugging and validation of the information

Upon completion of the questionnaire application period, a data file was extracted from the response database and subjected to a cleaning process comprising the following procedures [22]:

1. Identification of non-committed respondents through standardization of each questionnaire.

2. Detection of missing values. Cases exhibiting more than 10 % of missing data were excluded from the analysis, whereas those with lower percentages were imputed using the median.

3. Identification of extreme values through standardization of each item, with subsequent replacement by the median.

Following the data-cleaning process, the latent variables were validated using the indices proposed by Kock [23]. These indices included R^2 and adjusted R^2 for parametric predictive validity, composite reliability index, Cronbach's alpha index for internal validation, average variance extracted for convergent validity, variance inflation indices for multicollinearity, and Q^2 for nonparametric predictive validity.

D. Stage 4. Descriptive analysis of the items

Descriptive analyses were conducted using SPSS v.22 software. To elucidate the contribution of each item to its corresponding latent variable, the median was calculated as a measure of central tendency and the interquartile range (IQ) was determined as a measure of dispersion, given that the data were collected on an ordinal scale. Elevated median values indicated a high frequency of these activities, whereas lower values suggested a less frequent occurrence. Similarly, higher interquartile range values denote a lack of consensus regarding the item's median value, whereas lower values indicate a high degree of consensus or agreement among respondents.

E. Stage 5. Structural equation modeling

The structural equation modeling (SEM) technique was selected to validate the hypotheses because of its capacity to evaluate the relationship between latent variables integrated by items (as observed in this study) that can simultaneously function as dependent and independent variables. In this investigation, SEM was assessed using a partial least squares (PLS) approach, which is recommended for ordinal scales and small samples and does not necessitate the fulfillment of normality in variables. PLS-SEM is useful in predictive research where formative and reglective constructs exist, was used to evaluate social sustainability and manufacturing leadership [24] and to evaluate the impact of LMT on social sustainability [25].

The PLS-SEM analysis was conducted using WarpPLS v.8 software. Prior to interpreting the results, a series of indices that the model must satisfy were examined, including the average of the coefficients, average R2, and average adjusted R2 to measure the predictive validity of the model. Additionally, the averages of the variance inflation indices were calculated to assess collinearity, and the Tenenhaus index was used to measure the fit of the data to the model [23].

In the SEM analysis, three effects or relationships between variables were obtained, measured using a standardized parameter β as a measure of dependence, and their statistical significance was determined with a 95 % confidence level [26]. For each effect, the effect size (ES) is reported as a measure of the variance explained by the independent variable in the dependent variable. Furthermore, the R^2 value was associated with each dependent variable. Initially, the direct effects that enable the validation of the proposed hypotheses are reported; subsequently, the indirect effects that occur through the mediating variables are presented; and finally, the total effects, which comprise the sum of the direct and indirect effects, are reported.

F. Step 6: Sensitivity analysis

To determine the risks of having low levels of implementation in some of the variables and their items, three probabilities were reported in this study, which were obtained using WarpPLS v.8 software:

- Probability that a latent variable occurs at a high or low isolation level.
- Probability that two latent variables co-occur jointly in their combinations of high and low levels.
- The conditional probability that the dependent latent variable will occur at a high or low level given that the independent variable has occurred at one of its high or low levels.

IV. RESULTS

A. Descriptive analysis of the sample

A total of 1345 emails containing the questionnaire link were distributed to potential respondents, resulting in 312 responses, representing a response rate of 23.19 %. During the data filtering process, 26 responses were excluded due to a high percentage of missing data, leaving 286 responses for the analysis. Table 1 indicates that most respondents were male, experienced managers, and engineers, with the automotive sector being the most representative industry.

Table 2 presents the medians and interquartile ranges for the analyzed items, with four items exhibiting higher medians and three in the QUA variable, emphasizing MAC's culture of change and teamwork. For OPE, QUA assurance requires that they are responsible for inspecting their work and are adequately trained to make decisions that enhance product QUA. Regarding LMTs, it is primarily required that processes are standardized and errors are prevented; SUP are required to be certified and to maintain long-term relationships. Finally, the success of the QUA programs is demonstrated through the implementation of TQM and established metrics.

TABLE I
SAMPLE DATA

Category	Quantity	Percentage
Sex		
Man	193	67.48
Woman	93	32.52
Job position		
Manager	127	44.41

Engineer	112	39.16
Supervisor	47	16.43
Years in position		
1-2	20	6.99
2-5	49	17.13
5-10	86	30.07
>10	131	45.80
Industrial sectors		
Automotive	123	43.01
Electric	62	21.68
Electronic	48	16.78
Textile	27	9.44
Machining	14	4.90
Physician	12	4.20

TABLE II
DESCRIPTIVE ANALYSIS OF THE ITEMS

Management Commitment (MAC)	**M**	**RI**
The organization has a culture that fosters change.	3.58	1.72
Supervisors strive to foster teamwork by encouraging operators to cooperate and express their opinions.	3.54	1.71
Managers, engineers and operators constantly interact with each other.	3.54	1.61
The different departments of the plant are coordinated and in constant communication.	3.51	1.58
There is support and commitment from management in the execution of JIT.	3.48	1.51
Operators (OPE)		
Operators are responsible for inspecting their work.	3.70	1.65
Employees are trained to perform multiple tasks.	3.60	1.83
There are work teams to solve production problems and encourage employee participation.	3.57	1.76
Emphasis is placed on improving workers' skills and knowledge.	3.53	1.58
Many problems are solved by getting suggestions from workers.	3.52	1.76
Employees are hired for their ability to solve problems and work as part of a team.	3.47	1.72
Lean manufacturing tools (LMT)		
Processes are standardized.	3.68	1.60
A device to avoid errors (Poka-Yoke) has been implemented.	3.67	1.61
The design of the installation is product oriented.	3.66	1.55
The layout design is process oriented.	3.59	1.70
Suppliers (SUP)		
The company's suppliers are certified.	4.05	1.61
The company has long-term contracts with its suppliers.	3.76	1.56
Deliveries are received daily from most suppliers.	3.50	1.70
Suppliers are integrated into the company through a pull system.	3.47	1.78
QUA (QUA)		
Total QUA Management (TQM) principles and tools have been implemented.	4.21	1.57
QUA metrics are in place	4.17	1.60
A total productive maintenance (TPM) program has been implemented.	4.04	1.66
QUA initiatives are customer oriented.	3.96	1.59
Statistical control is used to control and reduce process variation.	3.90	1.72

B. Validation of the variables and the model

Table 3 presents the validation indices for the latent variables. As demonstrated in the final column, all the indices meet the minimum requirement. This indicates that sufficient parametric, nonparametric internal, and convergent predictive validity were present, and the variables exhibited no collinearity issues.

TABLE III
VALIDATION OF LATENT VARIABLES

Index	**QUA**	**SUP**	**LMT**	**MAC**	**OPE**	**Best if**
R^2	0.44	0.12	0.10		0.25	>0.02
R^2 Adjusted	0.43	0.12	0.09		0.25	>0.02
CRI	0.93	0.88	0.84	0.88	0.86	>0.7
CA	0.91	0.82	0.76	0.83	0.81	>0.7
AVE	0.73	0.66	0.58	0.60	0.51	>0.5
VIF	1.69	1.85	1.68	1.33	1.45	<3.3
Q^2	0.44	0.12	0.10		0.25	>0

CRI=Composite reliability index, CA=Cronbach's alpha, AVE= Average variance extracted, VIF=Variance inflation index

The validated variables were incorporated into the Structural Equation Model (SEM), and the efficiency indices demonstrated that the model exhibited adequate internal validity, possessed predictive capability, and lacked collinearity among the latent variables. Consequently, we proceeded with the interpretation of the SEM. The model indices are:

- Average path coefficient (APC)=0.329, P<0.001
- Average R-squared (ARS)=0.231, P<0.001
- Average adjusted R-squared (AARS)=0.227, P<0.001
- Average block VIF (AVIF)=1.441, ideally <= 3.3
- Average full collinearity VIF (AFVIF)=1.605, ideally <= 3.3
- Tenenhaus GoF (GoF)=0.378, large >= 0.36

C. Structural equation model

Figure 2 illustrates the PLS-SEM evaluated in WarpPLS 8.0, wherein the β value, associated p-value, and effect size (ES) of each direct effect proposed in Figure 1 as hypotheses are presented. Based on the p-values associated with the β parameters, it was determined that all hypotheses were accepted as they were less than 0.05.

In this investigation, there was only an indirect effect of MAC on QUA, with β=0.292, through the mediating variables OPE, LMT, and SUP, which were statistically significant at P<0.001.

As these two variables exhibited no direct effect, this indirect effect constituted the total effect between them in this study.

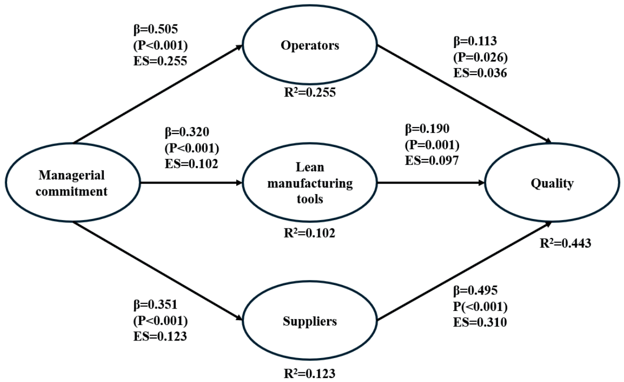

Figure 2. Evaluated model - validation of hypothesis

D. Sensitivity analysis

In WarpPLS v.8 software, the probabilities of occurrence were estimated for the variables. In this study, the probability that a variable is implemented adequately and efficiently is denoted when it has a standardized value greater than one, that is, P(Z>1), and is represented by the "+" sign. Conversely, the probability that a variable is implemented inadequately or inefficiently is denoted when the standardized value is less than minus one, that is, P(Z<-1), and is represented by the "-" sign. Table 4 illustrates the probabilities of the variables occurring independently and jointly, represented by "&", while the conditional probability is represented by "IF".

V. DISCUSSION OF RESULTS

Several conclusions and inferences can be drawn from the SEM and sensitivity analyses. The results indicate that MAC directly and positively affects OPE (H_1), with β=0.505, explaining up to 25.5 % of its variability. Furthermore, when MAC+ occurs, the probability of OPE+ occurring is 0.326, while the probability of OPE- is 0.000, as Li and Griffin [27]. Conversely, if MAC- occurs, there is a probability of OPE- of 0.281, which represents a significant risk in production lines, where OPE- does not contribute to the resolution of QUA issues and MAC- is only weakly associated with OPE+, with a probability of 0.094. A low MAC level directly affects the low commitment of OPE+, limiting managers' opportunities to integrate OPE+ perspectives for continuous improvement.

Similarly, the analysis demonstrated that MAC directly and positively affected LMT (H_2), with β=0.320, explaining up to 10.2 % of its variability. The occurrence of MAC+ favors the occurrence of LMT+ with a probability of 0.348, whereas the probability of LMT-is only 0.109. Effective manufacturing practices in the production process depend on managers who possess the decision-making authority to authorize process modifications. However, if MAC- occurs, indicating that managers are not integrated into the production process, LMT- can occur with a probability of 0.219, and LMT+ with a probability of 0.094. This suggests that production processes may be deficient, unproductive, and disorganized in the presence of limited MAC, which negatively impacts the product's final QUA and, according to García-Alcaraz, *et al.* [28], constitutes a high risk.

TABLE IV
SENSITIVITY ANALYSIS

Variable	Probability	MAC+	MAC-	OPE+	OPE-	LMT+	LMT+	SUP+	SUP-
		0.161	0.112	0.178	0.143	0.164	0.161	0.182	0.143
OPE+	0.178	&=0.052 IF=0.326	&=0.010 IF=0.094						
OPE-	0.143	&=0.000 IF=0.000	&=0.031 IF=0.281						
LMT+	0.164	&=0.056 IF=0.348	&=0.010 IF=0.094						
LMT-	0.161	&=0.017 IF=0.109	&=0.024 IF=0.219						
SUP+	0.182	&=0.063 IF=0.391	&=0.007 IF=0.063						
SUP-	0.143	&=0.017 IF=0.109	&=0.028 IF=0.250						
QUA+	0.133	&=0.035 IF=0.217	&=0.010 IF=0.094	&=0.028 IF=0.157	&=0.007 IF=0.049	&=0.031 IF=0.191	&=0.024 IF=0.152	&=0.031 IF=0.173	&=0.000 IF=0.000
QUA-	0.154	&=0.021 IF=0.130	&=0.028 IF=0.250	&=0.024 IF=0.137	&=0.045 IF=0.317	&=0.000 IF=0.000	&=0.059 IF=0.370	&=0.010 IF=0.058	&=0.073 IF=0.512

MAC also exhibited a direct and positive effect on SUP (H_3), with β=0.351, explaining up to 12.3 % of its variability. The significance of MAC on SUP is evident, as the occurrence of MAC+ is associated with a probability of 0.391 for SUP+ and only 0.109 for SUP −. This indicates that a positive relationship between managers and SUP fosters long-lasting trusting relationships contributing to QUA. However, MAC- is associated with SUP- with a probability of 0.250 and is only weakly associated with SUP+ with a probability of 0.063, suggesting that managers who are not committed to integrating SUP into their production processes generate limited communication, lack of coordination, and insufficient joint commitment to QUA.

The results further indicate that OPE directly and positively affect QUA (H_4) with β=0.113, explaining 3.6 % of its variability. The relatively small percentage may be attributed to OPE' limited decision-making authority, as they execute QUA plans and programs from the administration without aligning with SUP. If OPE+ occurs, QUA+ can occur with a probability of 0.157 and QUA- with a probability of 0.137, which are notably similar. This similarity may be due to the significant dependence of QUA on SUP in the Mexican Maquiladora industry. Similarly, if OPE- occurs, there is a risk of QUA- with a probability of 0.317, and QUA+ with a probability of 0.049.

Structural equation modeling (SEM) analysis revealed that LMT exhibits a direct and positive effect on QUA (H_5) with β=0.190, accounting for 9.7 % of its variability. Furthermore, the occurrence of LMT+ is associated with a 0.192 probability of QUA+ occurrence, whereas the conditional probability of QUA+ given LMT- is 0.000. This finding suggests that implementing LMT supporting QUA consistently yields benefits in production lines and is economically advantageous [29]. Conversely, the occurrence of LMT- was associated with probabilities of 0.370 and 0.152 for QUA- and QUA+, respectively.

The analysis indicates that SUP directly affects QUA, with β=0.495 (H_6), explaining 31.0 % of QUA variability, representing the second-largest effect in the analyzed model. Moreover, the occurrence of SUP+ was associated with probabilities of 0.173 and 0.058 for QUA+ and QUA-, respectively. The integration and co-responsibility of SUP in the manufacturer's production process enhances the manufacturer's QUA [30]. Conversely, their non-integration poses a risk that managers should avoid, as SUP- occurrence is associated with a 0.512 probability of QUA- occurrence and a 0.000 probability of QUA+ occurrence. This finding underscores that SUP integration consistently promotes QUA.

Although MAC does not directly relate to QUA, it demonstrates an indirect effect through OPE, LMT, and SUP, with β=0.292, accounting for 7 % of QUA variability. This relationship is corroborated by the observation that MAC+ occurrence is associated with probabilities of 0.217 and 0.130 for QUA+ and QUA −, respectively. This indicates that even with MAC+, QUA- remains possible owing to the involvement of the OPE, LMT, and SUP. Additionally, MAC- occurrence was associated with probabilities of 0.250 and 0.094 for QUA- and QUA+, respectively. These results suggest that MAC not only supports OPE, LMT, and SUP but also contributes to QUA by promoting the implementation of QUA assurance plans and programs and facilitating the allocation of necessary resources and supervision of their appropriate utilization.

VI. CONCLUSIONS AND INDUSTRIAL IMPLICATIONS

This study provides substantive evidence for the critical role of MAC in enhancing QUA and economic sustainability within the manufacturing industry. Through the application of a SEM, significant relationships between MAC and key operational factors—OPE, SUP, and LMT—have been identified. These findings offer valuable insights for managers and decision-makers seeking to improve their quality management practices and overall sustainability. The key conclusions are as follows:

MAC as a cornerstone: The results demonstrate that MAC serves as the foundation for an integrated quality management system. While MAC does not directly affect QUA, it exerts a substantial indirect effect (β = 0.292) through its influence on OPE, SUP, and LMT. This underscores the pivotal role of leadership in creating an environment conducive to quality improvement and sustainability.

SUP integration: The study reveals that SUP has the strongest direct effect on QUA (β = 0.495), explaining 31 % of its variability. This highlights the critical importance of effective SUP relationships in achieving and maintaining high-quality standards.

OPE empowerment: Although OPE has a smaller direct effect on QUA (β = 0.113), their role is essential in implementing quality protocols and identifying potential issues at the source. Empowering operators through training and involvement in decision-making processes can significantly enhance their contribution to quality outcomes.

LMT positively affects QUA (β = 0.190), accounting for 9.7 % of its variability. This emphasizes the importance of implementing lean practices to optimize processes, reduce waste, and improve efficiency.

These conclusions have several industrial implications and practical applications, including:

Cultivating leadership for QUA: Managers must prioritize their commitment to QUA initiatives, as this establishes the foundation for the entire organization. This can be achieved by implementing regular leadership development programs focused on quality management principles, establishing clear quality objectives, communicating them consistently across all levels of the organization, and allocating resources specifically for QUA improvement projects and initiatives.

Enhancing SUP relationships: Given SUP's significant impact on QUA, managers should focus on developing long-term, collaborative partnerships with key SUP, implementing joint QUA assurance programs and certifications with SUP, establishing clear communication channels and shared quality standards with SUP, and organizing regular SUP forums or exhibitions to foster innovation and alignment with QUA goals.

Empowering operators to leverage the potential of OPE in quality management, wherein managers should implement comprehensive training programs that focus on quality control techniques and problem-solving methodologies, establish operator-led quality circles or improvement teams to facilitate active participation in quality initiatives, and develop a suggestion system that incentivizes operators for identifying and resolving quality issues.

To optimize LMT, managers should conduct a thorough assessment of current processes to identify areas for lean implementation, prioritize the adoption of key lean tools such as 5S, Kaizen, and poka-yoke to standardize processes and mitigate errors, and implement visual management systems to enhance accessibility of quality standards and performance metrics for all employees.

Integrating quality management systems and managers should develop an integrated quality management framework that aligns MAC, OPE, SUP, and LMT initiatives. Additionally, they should implement cross-functional teams to oversee quality improvement projects, ensure collaboration between various departments, and utilize operational analytics and AI technologies to monitor quality metrics and identify areas for improvement in real time.

Finally, managers need to foster a culture of continuous improvement by establishing regular review processes to assess the efficacy of quality management practices, facilitate knowledge sharing and dissemination of best practices across the organization, and recognize and reward employees and teams that contribute significantly to quality improvement and sustainability efforts.

VII. LIMITATIONS AND FUTURE RESEARCH

While this study provides valuable insights, further research is necessary to expand our understanding of quality management and sustainability in industrial contexts. Future investigations should explore additional critical success factors, such as specific leadership styles and their impact on quality management effectiveness, examine the role of targeted training programs for operators and their influence on quality outcomes and sustainability, investigate how the integration of emerging technologies (e.g., Industry 4.0, AI, IoT) can enhance quality management practices and sustainability efforts, and conduct longitudinal studies to assess the long-term impact of managerial commitment on quality and sustainability performance. Furthermore, the applicability of these findings across diverse industrial sectors and cultural contexts should be explored to develop more generalizable insights.

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