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Lean Manufacturing Critical Success Factors for the Transportation Equipment Manufacturing Industry in Mexico

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ABSTRACT This research was carried out in the Mexican manufacturing industry, the second most important activity in the country's industrial sector, specifically in the transportation equipment manufacturing subsector, which generates 19% of the jobs in this industry. Thus, it is important to develop improvement strategies to strengthen the sector's competitiveness. Currently, Lean Manufacturing projects are considered the most important strategy for manufacturing companies to achieve world-class performance. However, such projects yield different results, depending on the level of Critical Success Factor (CSFs) implementation during their development. This work proposes the design and validation of an instrument to evaluate the implementation of CSFs during the project-improvement phase in the production of transportation equipment in the Mexican manufacturing industry. The instrument is made up of six CSFs selected from the reviewed literature on Lean Manufacturing methodology and improvement projects and measured through 31 items. The instrument was verified and empirically validated through exploratory factor analysis, confirmatory factor analysis, and reliability analysis, using the SPSS Amos ® software program and a sample of 240 valid surveys applied to experienced developers of Lean Manufacturing improvement projects. The results show that the proposed instrument holds enough statistical validity to be used by the companies in the sector in order to assess the impact of critical success factors on the development of improvement projects. Additionally, the survey can help companies to identify areas of opportunity by adopting the Lean Manufacturing methodology and fit models, to assess the interaction of the FCEs in achieving the expected results of improvement projects.

INDEX TERMS Critical success factors, lean manufacturing, confirmatory factor analysis, construct validation, mexican manufacturing industry, improvement projects.

I. INTRODUCTION

Today, project management has become a key activity in most modern organizations. Generally, projects must meet a wide variety of objectives; they involve numerous internal and external players and are carried out throughout various areas of activity [1]. However, the most important objective for project managers is quality, which can be ensured by identifying and eliminating the factors resulting in poor project performance. Thus, a better understanding of critical success factors (CSFs) and how to measure them is of essence [2]. Since the late 1960s, project management researchers have been investigating the factors that normally lead to project success, and their conclusions permeate the literature published for project management professionals. [3]. Because CSFs are the few key areas where "things must go well" for the manager's goals to be achieved and for the business to prosper [4], it is necessary to understand how to identify and address them effectively to ensure that the promised benefits can be achieved and that failures can be avoided [5].

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Some studies, such as Achanga's [6], have emphasized the need to examine and execute important factors which are considered critical to the successful implementation of any new productivity initiative in an organization.

As a result, there are numerous studies investigating CSFs as a quality initiative [7], and identifying and suggesting CSFs for Lean, Just In Time, Total Quality Management, Six Sigma, etc. Furthermore, the operation management literature and practice has shown and continues to show great interest in these topics, which has resulted in the many descriptions currently available. [8]. Additionally, numerous lists and models of critical success factors have been proposed throughout the literature [2]. Among the continuous improvement projects outlining the critical success factors are those for the Six Sigma [9]–[11]. In addition, the CSF for Lean Six Sigma have been discussed by [7], [12]–[14]; for Kaizen, by [15], [16]; for Total Quality Management (TQM), by [17]–[20]; for Total Productive Maintenance (TPM), by [21]; for Enterprise Resource Planning (ERP), by [4]; and for Lean Manufacturing (LM), by [22]–[25]. Identifying the Critical Success Factors (CSFs) for any continuous improvement initiative is important as it allows organizations to focus on such factors to ensure success [26].

Currently, manufacturing companies face constant pressure by their clients' requirements for speedy deliveries, new product development and innovation, more frequent deliveries of smaller batches, greater product variety, lower prices, zero quality defects, higher reliability and sometimes custom manufacturing. In some cases, these requirements are established in a contract which includes penalty clauses with monetary charges for non-compliance in delivery time, quantities, variety of products, quality or reliability [27]. Therefore, companies need to adopt methodologies such as Lean Manufacturing, considered the most important strategy for manufacturing companies seeking world-class performance, to allow them to become more prompt in their responses and be able to quickly adapt to unexpected changes.

In this sense, the benefits reported by companies that apply LM are such, especially within the Japanese industry, that many western companies decided to implement it in their own plants. However, as mentioned by [28], they began to notice differences in their results, which might be due to external factors or factors that are specific to each region. Considering such differences in the Lean Manufacturing implementation process, it can be assumed that there are a series of elements that must be present when developing improvement projects using LM tools.

On the other hand, in Mexico, the manufacturing sector is the most important in terms of total gross production as it generates 43% of the national total, holding 12.2% of economic units and 24.7% of all employed personnel [29]. In turn, the most important subsector within manufacturing is the fabrication of transport equipment, which encompasses the manufacturing of automobiles and trucks; bodies and trailers; motor vehicle parts such as steering systems, brake systems, and transmission systems; aerospace equipment; railway equipment; and boats and other transportation equipment, among others [30]. Due to the importance of the sector and the reported benefits of implementing the improvement methodology, it is common for large Mexican manufacturing companies to seek to implement Lean Manufacturing as a strategy to reduce production costs and eliminate unnecessary waste from the production process.

The foregoing reveals the need to identify the CSFs that affect the success of LM projects in the Transportation Equipment Manufacturing sector in Mexico in order to design and validate a measurement instrument that can be useful to companies as they collect the necessary data to evaluate the implementation of LM in their improvement projects.

This paper describes the necessary steps for the design and statistical validation of an instrument that can reliably measure the degree of CSFs implementation in Lean Manufacturing projects in Mexico. It is organized as follows: Section I introduces the topic, Section II provides a review of the background literature, the methodology followed is reported in Section III. The results and discussion are reported in section IV, the limitations of the work are presented in Section V. Finally, in Section VI the conclusion and future work are presented.

II. LITERATURE REVIEW

A. CRITICAL SUCCESS FACTORS

Critical success factors (CSFs) are characteristics, conditions, or variables that, if properly maintained or managed, can have a significant impact on the success of a competing company in a type of industry [31]. According to [32], aside from a few slight variations, critical success factors are similar in all quality improvement initiatives and seem relatively constant over time. Another important finding is that CSFs tend to be more related to how an organization addresses specific factors of change effort than to the methods of change themselves. Management support and organizational culture issues are often emphasized as especially critical.

Factors such as the top management involvement and commitment, Training and Education, project leadership, Customer Focus and Linking Lean to the Suppliers are known as key ingredients; that is, factors that are essential for the successful implementation of any quality improvement initiative [10]. Therefore, they are commonly found or transferred to the different improvement strategies. In fact, the main reason behind transferring concepts such as Six Sigma, Lean Manufacturing, or other improvement strategies to other organizations, is the success that they have led to in companies such as Motorola and Toyota [33].

To achieve the expected success or benefit in the implementation of LM improvement projects, the necessary resources must be provided and employees must understand the projects associated with LM [34], being Top Management Involvement and Commitment an FCE of Lean implementation [32], [34]. Likewise, you should be aware that the success of Lean Manufacturing largely depends on the Project

Leadership [35], since it is the leaders who must take the necessary measures to ensure that the Lean program is incorporated within an organization to achieve efficient progress and implementation of the improvement project [36].

Likewise, it is important to consider Training and Education as FCE [11], [32], [37]. Training workers on the principles of LM is required, because by receiving quality training and possessing essential educational qualifications, employees can carry out a successful implementation, increase their experience and learn to make decisions using their own understanding.

On the other hand, customers are the ones who determine the flow of value in the Lean manufacturing process, therefore, the company must be able to recognize the requirements of the customers and must organize the activities that would make the products available to them [38], in this sense studies such as those of Flynn *et al.* [39], made clear that the Customer Focus is an FCE that allows open communication with clients and helps them monitor their requirements, as well as helping to identify the necessary improvements if they are not met.

In the same way, the linking Lean to the Suppliers is considered a critical success factor for the development of LM projects [40], for its purpose to reduce costs and waste throughout the network of the company's supply chain, to ensure the success of Lean Manufacturing [34], which can be achieved by creating a relationship between suppliers and manufacturers.

Due to the foregoing, the development and validation of a reliable instrument that allows the collection of data on the FCE that affect the development of LM projects in the specified study sector is important. This is in accordance with what was mentioned by [15], who affirms that by understanding the CSFs for the implementation of a system, an organization can successfully determine the difficulties that critically affect the process, eliminating or avoiding any problem that may contribute to its failure.

III. METHOD

This study used a cross-sectional survey design to collect data on the implementation of LM's CSFs when developing projects aiming to improve the transportation equipment manufacturing industry in Mexico. The methodology adopted for the development and validation of the data collection instrument (survey) is the one commonly used in the social sciences to measure variables through the psychometric method [41]. This method has been used by researchers as a reference for survey development and validation [42], [43]. The survey design and validation process was developed in three stages, which are analyzed below: A) Instrument design, which consists of the definitions of the construct and the indicator, B) Instrument administration, which includes data collection and, C) Statistical analysis for instrument validation, which consists of assumption verification, data analysis through factor analysis, and construct validation.

TABLE 1. Conceptual definition of constructs.

Construct	Description
Top Management Involvement and Commitment (TMIC)	Any successful initiative requires the participation of top management and the provision of appropriate resources and training [44]. Without the continued support and commitment of top management, the true importance of the initiative will be in doubt and the energy behind it will weaken [45], [10].
Project leadership (PL)	Leadership effectiveness allows employee involvement in continual improvement activity, effective communication and collaboration, and better dissemination of operation information and organization strategy in managing quality improvement [7].
Training and Education (TE)	A comprehensive Training and Education program provides the necessary tools, knowledge and methodology towards systematic approach on problem solving. Without proper Training and education, a plant is not likely to succeed with its lean implementation [46] [8].
Customer focus (CF)	Focusing on customer need and satisfaction should be the most important practice for implementing quality initiatives [47]-[49]. Therefore, organizations must be aware and responsible for listening to the voice of customers [50], meeting their needs and expectations [51], and predicting their demand [52].
Linking Lean to the Suppliers (LLS)	This construct is important to improve the quality design product, improve the system and management of purchase orders, improve the long-term cooperative relationship and improve the strategic partnership [53], [54]. This linkage is mutually beneficial since they will help both parties to compete more effectively in the market [55].
Benefits (B)	A benefit is associated with a positive action or result that favors people and the organization [56], the benefit of implementing the LM methodology is reflected through a gradual reduction of activities and elements that do not add value to the organization [57].

A. INSTRUMENT DESIGN

The first step in instrument design is to identify the constructs that will be considered for the study. Thus, an extensive literature review was performed using the Ebsco Host, Elsevier, Emerald, Gale, IEEE, Springer databases, Wiley and Google Scholar. The study used included publications from the last ten years regarding the CSFs in the Implementation of improvement projects using LM techniques and tools. The key words used in the search of articles were Lean Manufacturing, Critical Success Factors, Lean Six Sigma, Kaizen, Total Quality Management, and Just in time.

One hundred and sixty-five (165) articles were reviewed to obtain the CSFs with the highest number of mentions in the literature; a total of 21 CSFs was identified. Next, the factors making up slightly more than 65% of the mentions were selected to serve as the basis for the data-collection instrument design. Table 1 lists these CSFs with their respective conceptual definitions and references. The factors resulting from this analysis and conforming the object of this study are: Top Management Involvement and Commitment (TMIC), Proyect Leadership (PL), Training and Education (TE), Customer Focus (CF), Linking Lean to the Suppliers (LLS) and Benefits (B).

1) VARIABLES OPERATIONALIZATION

The six CSFs represent the latent variables studied through the survey. Since these variables cannot be directly measured, it was necessary to operationalize them [58], [59]; that is, to convert the subjective variables into directly observable objective ones [60], [61]. The final survey would be the product of such operationalization. To achieve it, it was necessary to work from the conceptual definitions in Table 1. Next, a series of indicators were to be listed for each construct, and then at least one item was to be provided that would allow the indicator to be measured.

The process of operationalization of the latent variable Project Leadership (PL) is explained next as an example. The PL variable is defined by three indicatorsin accordance with the degree to which it: encourages participation, identifies training needs, and seeks the group members' well-being. Each indicator is, in turn, followed by the items used to measure it, along with their respective references. Thus, the indicator labeled as "Encourages participation" is measured through item PL1; and "Identifies training needs," by items PL2 and PL3. On the other hand, items PL4 and PL5 measure the "Seeks the group members' well-being" indicator. The operationalization of the six latent variables and, consequently the complete survey, is available in the Table 2.

The scoring instrument developed in this study uses a five-point Likert scale, representing a range of perception from never (1) to always (5). The use of the five-point Likert scale in this type of operations management study is a popular option to measure latent variables through a set of related elements [56], [71].

2) CONTENT VALIDITY

The survey was reviewed by six LM experts, in both the academic and the industrial fields, to check for content validity. The relevance and clarity of the questions, the clear meaning of the jargon commonly used in industry, and the time required to complete the entire survey were evaluated. Then based on the six experts' comments, the instrument was modified. Its final structure consisted of five sections: The first section offers a brief introduction to the survey's objectives, while the second one collects information on companies' demographic data. Section three evaluates the use of CSFs in LM projects, and section four contains an analysis of the LM tools. The last section aims to find out the benefits for companies that implement improvement projects using LM.

TABLE 2. Operationalization of the six latent variables.

Construct	Indicators	Items
Top Management Involvement and Commitment (TMIC)	Project monitoring	*TMIC1.* Top management support and actively participate in LM improvement activities (training, selecting project, stage review and results evaluation) [62].
	Project improvement strategies	*TMIC2.* Consider the quality improvement as a way to increase success [46].
		TMIC3. Leadership encouraging employee participation in LM implementation [63].
	Communication	*TMIC4.* Leaders to have regular written communication on LM news and successes of projects [63].
	Availability of financial resources	*TMIC5.* Availability of resources for employee training in the company [19].
Project leadership (PL)	Encourage involvement	*PL1.* Strongly encourages employee involvement in LM projects [64].
	Detect training needs	*PL2.* Helps my work group see areas in which we need more training [65].
		PL3. Explains rules and expectations to the work group [64].
	Seeks the well-being of group members	*PL4.* Shows concern for work group members´ well-being [64].
		PL5. Takes the time to discuss work group members' concerns patiently [65].
Training and Education (TE)	Program formal training	*TE1.* Establishing the formal training programs [66].
	Leadership development	*TE2.* Training in interactive skills (such as communication skills, effective meeting skills and leadership skills) [46] [19].
		TE3. Our plant has a high skill level, compared with our industry (reverse coded) [67].
	Technical training	*TE4.* The organization provides adequate technical training for my team [67].
	Continuous training	*TE5.* Training is available for members of this team when we need it [67].
Customer focus (CF)	Common objectives	*CF1.* Involving customers on projects [68].
		CF2. Extent to which customers are actively involved in future product [7].
		CF3. Extent to which customers share current demand information with marketing department [7].
	Customer satisfaction	*CF4.* Selecting projects that impact favorably on customer satisfaction [68].
	Customer requirements	*CF5.* Evaluate and predict customer requirements on a regularly [62].
Linking Lean to the Suppliers (LLS)	Supplier participation in projects	*LLS1.* Suppliers are involved in LM projects [63].
		LLS2. Suppliers actively participate in improvement projects, and the organization provides support and review supplier's improvement activities [62].
		LLS3. Extent to which problems are jointly solved with our suppliers [7].
	Supplier relationship	*LLS4.* Long term relationship and working partnership with key supplier is established [69].
	Supplier selection	*LLS5.* Extent to which quality is considered as your number one criteria in selecting suppliers [7].
Benefits (B)	Improved quality	*B1.* Reduced costs of poor quality [19].
	Time reduction	*B2.* Improved customer satisfaction [19].
	Waste reduction	*B3.* Improved quality and less rework [19].
	Competitive advantage	*B4.* Delivery performance [70].
	Improved quality	*B5.* Reduction of the amount of waste [70].
	Time reduction	*B6.* Improved competitive advantage [19].

B. INSTRUMENT ADMINISTRATION

This study focuses on large manufacturing companies (those with over 250 workers) within the transportation equipment manufacturing sector in Mexico. The companies were identified through the INEGI's (National Institute of Statistics and Geography, for its Spanish acronym) database and represent 23% of the total of large companies in the Mexican manufacturing sector [29]. The survey's target participants were employees in middle to high management positions; that is, employees ranking from supervisors, on the lower end, to project leaders, engineers, managers, and CEOs with experience in the implementation of LM projects. A total of 1,580 surveys were sent via different means such as SurveyGizmo, email, personal visits, and LikedIn. The response rate was of 17%, with 270 completed surveys from 102 different companies. The responses demographics were as follows: The position reporting the highest participation was that of Product and Process Engineer, comprising 20%; and there was greater male participation (85%); on the other hand, 71% of those surveyed had less than 5 years of experience in the studied sector; and the subsector with greater participation was the aerospace equipment manufacturing (39%). The characteristics of the sample can be seen in Table 3 below.

TABLE 3. Sample characteristics.

Characteristics	Frequency	Percentage
Gender		
Female	40	15
Male	230	85
Manufacturing sub sector		
Aerospace equipment	105	39
Cars and trucks	43	16
Other parts for motor vehicles	35	13
Electrical and electronic equipment for automotive vehicles	33	12
Seats and interior accessories for automotive vehicles	19	7
Trucks and tractors	14	5
Gasoline engines and their parts for automotive vehicles	8	3
Transmission systems for motor vehicles	5	2
Bodies and trailers	5	2
Others	3	1
Experience		
Less than 2 years	95	35
From 2 to 5 years	97	36
From 5 to 10 years	46	17
More than 10 years	32	12
Position		
Product and process Engineer	54	20
Product Design / Development engineers	49	18
Project Leadership	32	12
Supervisor	32	12
Continuous improvement engineer	24	9
operations manager	16	6
Quality engineer	14	5
plant manager	14	5
Others	35	13

C. STATISTICAL ANALYSIS FOR INSTRUMENT VALIDATION

Questionnaire validation involves two tests: reliability and validity. Factorial analysis was used to measure the reliability and validity of indirectly observable variables [72]. First, four important aspects to consider in the validation of surveys were verified [73], [74]: missing data, outliers, assumptions of univariate and multivariate normality, and multicollinearity. To avoid missing data, only complete surveys were registered in the program used to administer the survey. Then the database was verified to identify outliers, observations with a unique combination of identifiable characteristics that clearly differ from the other observations [74]. This was achieved using the Mahalanobis distance. A total of 30 surveys identified as outliers were eliminated as they did not meet a conservative level of statistical significance, where according to what Kline recommended, $p < 0.001$ [75]. Thus, the following calculations for survey validation were made considering 240 responses alone. The foregoing was necessary in order to improve the normality of the database since by complying with this assumption, the maximum likelihood method can be used to extract the factor [76] just as was done by this work of research.

Verification of univariate normality was required as a necessary, albeit insufficient, condition for multivariate normality. [77]. To measure the normality of variable data, DeCarlo [77] suggests relying on skewness and kurtosis; therefore, those two indices were used to measure the univariate normality of each of the variables in the instrument. This resulted in absolute values lower than 1.96 (which corresponds to a .05 error level) for skewness and absolute values of less than 3 for kurtosis, as can be seen in Table 4. Such results show that the data have univariate normality, as suggested [77] when stating that, under normal distribution, the skewness measure must have a value of ± 1.96 and the standardized kurtosis, a value equal to or lower than 3.

TABLE 4. Results from the construct validity tests.

Construct / Variable	Skewness	Kurtosis	VIF	Factor loading	Eigenvalues	Composite reliability	Cronbach's alpha
TMIC							
TMIC1	-0.982	0.399	3.707	0.860			
TMIC2	-1.682	2.986	2.003	0.682			
TMIC3	-1.298	1.291	3.158	0.806	1.941	0.833	0.890
TMIC4	-0.857	0.184	2.935	0.795			
TMIC5	-0.798	-0.108	3.176	0.806			
PL							
PL1	-0.853	0.031	3.193	0.805			
PL2	-0.747	-0.102	3.168	0.811			
PL3	-0.881	0.591	4.368	0.882	14.097	0.832	0.929
PL4	-0.820	0.128	4.705	0.895			
PL5	-0.621	-0.277	3.874	0.864			
TE							
TE1	-0.865	0.312	3.031	0.802			
TE2	-0.706	-0.229	5.022	0.834			
TE3	-0.792	0.292	2.738	0.810	1.049	0.832	0.900
TE4	-0.757	-0.020	3.602	0.867			
TE5	-0.349	-0.259	2.955	0.637			
CF							
CF1	-0.073	-1.053	2.161	0.666			
CF2	-0.624	-0.322	2.462	0.750			
CF3	-0.580	-0.509	2.368	0.691	1.165	0.833	0.850
CF4	-0.936	0.958	2.779	0.770			
CF5	-0.784	-0.010	2.639	0.814			
LLS							
LLS1	-0.240	-0.788	3.779	0.790			
LLS2	-0.494	-0.483	3.500	0.785			
LLS3	-0.499	-0.453	3.812	0.874	1.421	0.832	0.909
LLS4	-0.610	-0.375	2.995	0.809			
LLS5	-0.627	-0.410	2.733	0.784			
B							
B1	-1.305	2.097	2.028	0.680			
B2	-1.201	1.385	2.601	0.790			
B3	-1.176	1.353	3.021	0.860	2.556	0.857	0.886
B4	-0.962	0.825	2.782	0.709			
B5	-1.182	1.606	2.673	0.704			
B6	-1.002	0.590	2.225	0.745			

Next, multivariate normality was assessed through the Mardia test, which is based on the normalized value of multivariate kurtosis [78]. The procedure consists of comparing the Mardia coefficient for the data under study with a calculated value obtained from the formula $p(p + 2)$, where p is the number of variables observed in the model [72]. This assumption was verified by contrasting the value of the multivariable kurtosis obtained through the SPSS Amos program with the value calculated through the proposed formula. Considering the 31 variables contained in the survey, the calculation yielded a value of 1023; that is, a greater value than the multivariate kurtosis index obtained through SPSS Amos. By meeting the condition that the calculated value be greater than the obtained value of 184.347, the assumption of multivariate normality in the data set was also met [79].

Finally, the study checked for presence of multicollinearity in the data to eliminate the possibility of two or more variables being highly correlated and, therefore, measuring the same construction [79]. Two tests were used for this purpose: the first one calculated the bivariate correlations since according to Kline [75], any pair of variables with a correlation greater than 0.85 should be interpreted as evidence of possible problems; that, however, did not occur in this analysis, where the highest bivariate correlation was 0.79. The second test analyzed the variance inflation factors (VIF), which verify whether the variable could be redundant by having values greater than 10 [75]. In the study, the results of the VIF indicated a maximum value of 5.022 (see Table 4). Thus, based on the two tests carried out, it is possible to conclude this data set shows no multicollinearity problems.

1) FACTOR ANALYSIS

The exploratory factor analysis (EFA) of the correlation matrix established the latent dimensions, and the results were used as an indicator of the validity of each construction studied. According to [80], instrument validity is the degree to which an instrument truly measures what it intends to measure. In factor analysis, the maximum likelihood estimate was used to extract the factor and varimax rotation. Factor rotation is essential in EFA. In fact, it is considered by many as the most important tool in EFA interpretation [73]. In this study, a varimax rotation was performed since, aside from distributional assumptions, it is less likely to produce improper solutions or factors that are not correlated [81].

The first step when conducting an EFA is to assess sample adequacy by calculating the Kaiser Meyer Olkin (KMO) index, which provides a measurement that determines whether the partial correlations between the variables are small. The resulting sampling adequacy of 0.938, which is greater than 0.9, indicates that current data is adequate for the analysis [82]. Bartlett's sphericity test is another method used to determine the viability of a factor analysis, which was also significant ($p < 0.001$) showing enough correlation between the elements, which confirms the applicability of factor analysis. The next important step of an EFA is the elimination of insignificant factor loads. In this regard, Hatcher [83] mentions that at least 0.4 loads of each element in its respective factor are considered adequate for that factor. The factor loadings of the 31 items were significant, so it was not necessary to eliminate items. The EFA allowed for the identification of six factors, consisting of a total of 31 variables with significant loads and which explain 71.707% of the data's total variance. It is worth mentioning that the eigenvalues of all the factors were greater than 1. Table 5 shows the resulting factorial structure for the 31 items for the total sample.

Two criteria were used to test the adequacy of the sample size: the first is the Hoelter's Critical N [84], which indicated 167 surveys as sufficient sample size for $\alpha = 0.01$; the second criterion was that suggested by Hair *et al.* [74] in which the appropriate value of a load factor is according to the size of the sample; The present work is based on 240 valid surveys, so load values higher than 0.40 are considered significant ($\alpha = 0.05$) [74].

TABLE 5. Factorial structure of the 31 items.

Items	Factors					
	1	2	3	4	5	6
PL1	0.692					
PL2	0.675					
PL3	0.755					
PL4	0.771					
PL5	0.772					
B1		0.554				
B2		0.711				
B3		0.763				
B4		0.687				
B5		0.707				
B6		0.603				
TMIC1			0.727			
TMIC2			0.551			
TMIC3			0.730			
TMIC4			0.565			
TMIC5			0.623			
LLS1				0.802		
LLS2				0.787		
LLS3				0.721		
LLS4				0.601		
LLS5				0.538		
CF1					0.555	
CF2					0.706	
CF3					0.706	
CF4					0.475	
CF5					0.641	
TE1						0.441
TE2						0.748
TE3						0.439
TE4						0.496
TE5						0.692
% Variance explained	45.474	8.244	6.260	4.585	3.758	3.384
Cumulative variance	45.474	53.719	59.979	64.565	68.323	71.707

After the EFA, a Confirmatory Factor Analysis (CFA) was performed using SPSS Amos, version 23. Again, univariate and multivariate normality were tested for, and outliers and multicollinearity of the data were sought. Any problems regarding the first two assumptions were ruled out, and the sample size of 240 surveys was kept for subsequent tests.

The validity of a measurement model depends on establishing acceptable levels of goodness of fit and finding specific evidence of construct validity. According to Kline [75], at least the following fit indices in the model must be estimated when validating a measurement model: the χ^2/df statistic, the mean square error of approximation (RMSEA), the standardized root mean residual (SRMR) and the comparative fit index (CFI); and at least one incremental index and one absolute index must be reported. In addition, it is recommended to add the fit index of standard parsimony (PNFI) to compare models of different complexity.

TABLE 6. Model fit indices estimates for the measurement model.

Goodness of fit Statistical	Obtained value	Recommended values for satisfactory model fit to date	References
χ^2/df	1.682	3, 2 or less	[85]
TLI	0.941	Greater than 0.9	[74], [76]
CFI	0.948	Greater than 0.9	[74], [76]
RMSEA	0.053	Less than 0.08	[74], [86]
SRMR	0.047	Less than 0.05	[87]
PNFI	0.788	Of 0.5 to 1	[88]

TABLE 7. Correlations among constructs, average variance extracted and squared correlations.

	TMIC	PL	TE	CF	LLS	B
TMIC	**0.628**	0.545	0.626	0.372	0.319	0.397
PL	0.738	**0.726**	0.615	0.393	0.335	0.266
TE	0.791	0.784	**0.630**	0.412	0.440	0.305
CF	0.610	0.627	0.642	**0.548**	0.501	0.426
LLS	0.565	0.579	0.663	0.708	**0.654**	0.392
B	0.630	0.516	0.552	0.653	0.626	**0.563**

Note: The values below the main diagonal represent the correlations between constructs, significant at the 0.001 level. The values of the main diagonal correspond to the Average Variance Extracted (AVE) of the constructs. Values above the main diagonal are the squared correlations.

The confirmatory factor analysis (CFA) results indicate an excellent fit, with χ^2/df being lower than 2.0. In addition, the CFI and TLI values are greater than 0.9, the RMSEA value is lower than 0.08, and the SRMR value falls below 0.05. Such goodness of fit indices confirm the validity of the measurement model. Finally, a PNFI value of 0.788 shows an acceptable level of complexity (see Table 6), and the R^2 value for each indicator is between 0.52 and 0.90. The results suggest that these six constructions can be used to measure the implementation of LM in improvement projects of the manufacturing and transportation equipment industry in Mexico. These constructions are shown graphically in the proposed measurement model (Fig. 1).

Construct validity was measured through the results of factor analysis. The following is the convergent, discriminant and nomological evaluation as recommended by Hair [57].

2) CONVERGENT VALIDITY

Convergent validity is measured through the average variance extracted index (AVE), in which any AVE value greater than 0.5 indicates good convergent validity, confirming that a set of elements are indicators of a specific construction [74] as they have a high proportion of variance in common. The AVE values of the constructs or latent variables in this study are shown by the main diagonal on the concentrated matrix in Table 7, as can be seen, all of them are greater than 0.5.

Likewise, the internal consistency of the instrument was verified using Cronbach's alpha and the Composite Reliability coefficient (CR), the latter having the characteristic of not depending on the number of items in the latent variable [81]. In both criteria the minimum acceptance rule, according to Nunally [89], is a reliability of 0.7 in the early stages of research and of a strict 0.8 in basic research. It was found that the instrument developed by this study shows enough

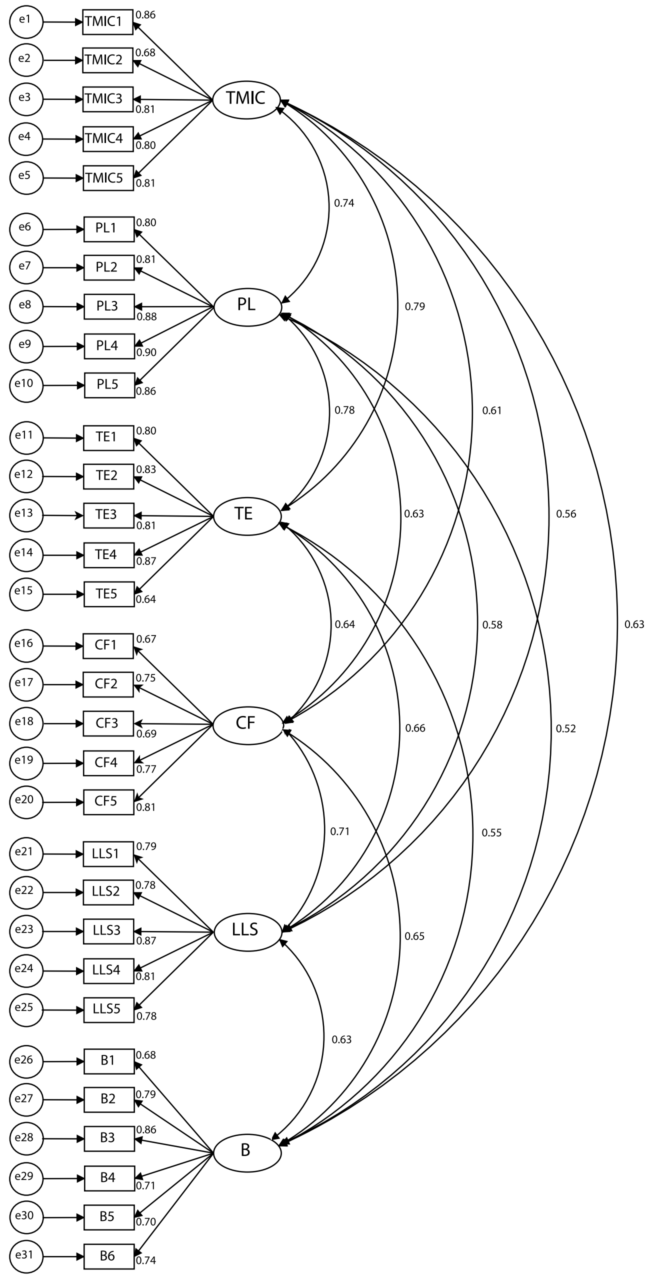

FIGURE 1. Proposed measurement model for LM CSFs for the transportation equipment manufacturing industry in Mexico.

convergent validity in all latent variables as it features Cronbach's alpha values equal to or greater than 0.850 and CR values greater than 0.832 (Table 4).

3) DISCRIMINANT VALIDITY

Discriminant validity tests the extent to which one construct is truly different from the others. One way to estimate this indicator is by comparing the AVE values for one of the two constructions with the squared correlation. The AVE must, then, be greater than the squared correlation to confirm that the two constructions are independent of each other. Table 7 shows that the constructions have an AVE value greater than the square of all their correlations. Therefore, discriminant validity shows evidence that each instrument construction is unique and can be used to analyze part of the phenomenon.

4) NOMOLOGICAL VALIDITY

Finally, the nomological validity was evaluated, and it was possible to confirm that the correlations between constructs, within a measurement theory, made sense since they were positive and significant. This makes sense as the constructs were defined to achieve a successful implementation of improvement projects under the LM methodology. The matrix in Table 7 shows how the constructs are related to each other.

IV. RESULTS AND DISCUSSION

The objective of this research was to design and validate a data collection instrument (survey) that would evaluate the effect of CSFs on the implementation of LM improvement projects in the transportation equipment manufacturing sector in Mexico. The instrument's design included the process of operationalization of variables, which allows non-observable variables to be measured directly through measurable indicators [59], as is the case with CSFs. In order to verify the validity of the instrument, exploratory and confirmatory factorial analyses were conducted, and goodness of fit indices were estimated, all of them confirming the measurement model's good fit with respect to the data. Construct validity was evaluated by means of the CFA which confirmed that the measured elements truly reflect the theoretical latent variables that were to be measured. Finally, the study assessed the three types of construct validity (convergent, discriminant and nomological), and each one yielded a statistically satisfactory result.

During the instrument validation stage, it was possible to carry out an analysis of the responses obtained, which allowed for an evaluation of the perceived level of CSFs implementation when carrying out LM improvement projects in the studied sector. Table 8 shows the general mean and standard deviation for each factor, which were used to investigate the level of CSFs implementation perceived by respondents.

Average values range from 3.774 to 4.243 with average standard deviation of 0.807, showing a good level of implementation in LM practice. The information showed that CSF Benefits (B), along with Top management Involvement and Commitment (TMIC), with values of 4.243 (±0.861) and 4.240 (±0.884) respectively, were perceived as the most important factors when carrying out LM Projects. This is consistent with what was reported by [90] [91]. The third place is held by the Project Leadership (LP) factor, with an average value of 4.080 and standard deviation of 0.925, followed by the Training and Education factors (3.920 ± 0.916) and the Customer Focus (3.868 ± 0.995); finally, the respondents perceived that the CSF Linking Lean to the Suppliers (LLS) has a lower level of implementation with values ranging from 4.816 to 2.71, with an average evaluation of 3.774. It should be noted that the six factors were considered by respondents

TABLE 8. Average rating of CSF by degree of LM implementation.

Construct	Variable	Mean	SD	Average mean	Average SD	Rank
Top Management Involvement and Commitment (TMIC)	TMIC1	4.17	0.924	4.240	0.884	2
	TMIC2	4.54	0.725			
	TMIC3	4.37	0.857			
	TMIC4	4.03	0.985			
	TMIC5	4.09	0.931			
Project leadership (PL)	PL1	4.15	0.904	4.082	0.925	3
	PL2	4.15	0.874			
	PL3	4.08	0.900			
	PL4	4.10	0.944			
	PL5	3.93	1.003			
Training and Education (TE)	TE1	4.09	0.933	3.920	0.916	4
	TE2	4.03	0.959			
	TE3	4.12	0.874			
	TE4	4.11	0.885			
	TE5	3.25	0.930			
Customer Focus (CF)	CF1	3.30	1.231	3.868	0.995	5
	CF2	3.90	0.995			
	CF3	3.86	1.028			
	CF4	4.18	0.823			
	CF5	4.10	0.900			
Linking Lean to the Suppliers (LLS)	LLS1	3.50	1.120	3.774	1.043	6
	LLS2	3.55	1.149			
	LLS3	3.85	1.012			
	LLS4	3.98	0.961			
	LLS5	3.99	0.974			
Benefits (B)	B1	4.21	0.883	4.243	0.861	1
	B2	4.33	0.825			
	B3	4.27	0.842			
	B4	4.23	0.833			
	B5	4.30	0.805			
	B6	4.12	0.976			

as "always" and "almost always;" that is, as normally present when implementing this type of improvement project.

Top management Involvement and Commitment were perceived by respondents as one of the most important elements when carrying out LM projects. Any successful initiative such as LM requires senior management involvement as well as the deployment of appropriate resources and training [44]. Senior management's commitment to the understanding, implementation, and goals within the organization has the greatest influence on the performance and success of any LM improvement project. Without the continuous support and commitment from the top management, the true importance of the initiative will seem questionable and the thrust behind it will weaken [10], [45].

Project leadership is considered a very important CSF when implementing LM projects, as it addresses the critical role of fostering quality improvement and employee engagement, communicating effectively, engaging in project selection and evaluation, and guaranteeing the attainment of the project's goals and objectives by a specified due date. Therefore, authors such as de Kuei and Madu [92] believe that leadership is key to the success of any improvement project. Without adequate leadership, there is no reason to have the project implemented. This last statement is supported by Eckes [93], who claims that improvement projects such as LM fail due to the leadership's weakness in project management skills.

As was previously mentioned, a successful initiative like LM requires adequate training since a comprehensive LM training program provides the tools, knowledge, and methodology necessary for a systemic approach to problem solving [46]. A good training program must be well-defined and have the adequate duration to equip employees with the necessary quality-related knowledge and problem-solving skills to develop a successful LM improvement project. This is supported by Jafari [94], who also believes that continuous training should be applied through seminars, training courses and conferences, without forgetting the role of Education in training. Netland's opinion [8] endorses the foregoing as it holds that without adequate training and education, a plant is unlikely to be successful in the efficient implementation of improvement projects such as LM.

According to the respondents' perception, the next most important CSF for the successful implementation of LM is Customer Focus. In fact, CF is considered the most important part of the continuous improvement process. Consequently, focusing on customer needs and satisfaction should be the most important practice for implementing quality initiatives [47]–[49]. Therefore, organizations must be aware of customers opinions and be responsible for heeding them [50], [94], meeting their needs and expectations [51] and predicting their demands [52]. The need to consult clients has become increasingly important when trying to successfully implement a project [95]. In fact, Manley [96] found that the degree to which clients are personally involved in the implementation process will impact on the variation in their support for that project.

On the other hand, the CSF Linking Lean to the suppliers featured the lowest level of implementation according to the respondents' perception. This is consistent with Antony and Desai [97], who also found that respondents paid less attention to the Linking Lean to the Suppliers factor. The reason is that a collaborative relationship with suppliers occurs when top management prioritizes product quality and delivery time performance over price in vendor selection, quality management system recognition, and tool preparation measurement to assess the quality of the company's suppliers [39]. Therefore, it is essential to have a mechanism that ensures that only good quality will be received from suppliers. Especially during the initial stage, leadership plays a key role in guaranteeing the suppliers' participation in the development of products and LM improvement project.

V. LIMITATIONS

This research work achieved the objective of designing and validating an instrument to evaluate the implementation of the CSFs in LM improvement projects in the studied sector. However, there are two main limitations to this work. First, this survey encompassed only the transportation equipment manufacturing sector of the Mexican manufacturing industry. However, the authors consider that the instrument could be used in other industrial sectors of any country or countries with similar conditions to those in Mexico. Nonetheless, they recommend checking the validity of the instrument first, and adjusting if necessary, before using it in different sectors from that for which it was designed and validated. Secondly, the CSFs considered for the development of the instrument were the product of an extensive literature review. A considerable list of CSFs was used, and only the CSFs with the highest number of mentions were chosen. Thus, it is likely that there are CSFs influencing LM improvement projects, albeit to a lesser extent, which were not included in the instrument.

VI. CONCLUSION AND FUTURE WORK

The objective of the study was to develop a statistically valid survey to evaluate the CSFs that influence the implementation of improvement projects which follow the Lean Manufacturing methodology in the manufacturing industry of transportation equipment in Mexico. In addition, the administration of this survey can help identify areas for improvement when carrying out LM projects. The data for the study was obtained from a sample of 240 respondents and the measurement model was tested using SEM. Based on AVE and CFA it was confirmed that all constructs are valid and reliable for research. Regarding the level of CSF implementation, perceived by the respondents when carrying out the LM improvement project, it was found that the six factors are considered by the respondents as "always" and "almost always;" that is, as present when implementing this type of improvement project, which can be considered a positive progress in the implementation of LM projects. The CSFs with the highest level of implementation are Benefits, and Top management Involvement and Commitment. Therefore, it can be concluded that when carrying out a LM project, greater benefits can be expected if there is a higher level of commitment from the high direction. As further research opportunities, the authors are interested in studying the structural relationships between LM projects and the benefits obtained from developing them, in the transport equipment manufacturing subsector. The survey developed in this study can be used in relevant manufacturing industries with characteristics similar to this subsector; thus, the authors will later seek to apply and validate the instrument in other manufacturing sectors of the nation in order to support, through LM improvement projects, the improvement in the competitiveness of its second most important industrial activity.

DISCLOSURE STATEMENT

The authors declare no conflict of interest.

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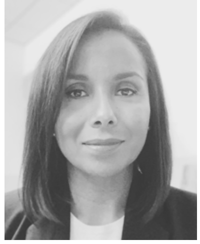

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