The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/2040-4166.htm

Modeling critical success factors of lean six sigma in higher education institutions

Carlos Gastelum-Acosta
Unidad Académica San Luis Río Colorado, Universidad Estatal de Sonora, San Luis Río Colorado, México and Universidad Tecnológica de San Luis Río Colorado, San Luis Río Colorado, México

Jorge Limon-Romero, Yolanda Baez-Lopez and Diego Tlapa
Facultad de Ingeniería, Arquitectura y Diseño, Universidad Autonoma de Baja California, Ensenada, México

Jorge Luis García-Alcaraz
Departamento de Ingeniería Industrial y Manufactura, Universidad Autonoma de Ciudad Juarez, Juarez, Mexico

Cesar Puente
Facultad de Ingeniería, Universidad Autonoma de San Luis Potosi, San Luis Potosi, Mexico, and

Armando Perez-Sanchez
Facultad de Ciencias de la Ingeniería y Tecnología, Universidad Autonoma de Baja California, Ensenada, Mexico

Received 10 March 2021
Revised 14 July 2021
25 November 2021
14 May 2022
Accepted 14 May 2023

Abstract

Purpose – This paper aims to identify the relationships among critical success factors (CSFs) for lean six sigma (LSS) implementation in higher education institutions (HEIs).

Design/methodology/approach – An extensive literature review was conducted to design the survey instrument, which the authors later administered in Mexican public HEIs to identify the existing relationships among the CSFs and their impact on the benefits obtained from implementing LSS projects. The data were empirically and statistically validated using exploratory and confirmatory factor analysis. Additionally, the authors applied the structural equation modeling (SEM) technique on SPSS Amos to validate the nine hypotheses supporting the research.

Findings – The results suggest that the success of LSS projects in HEIs is highly bound to a serious commitment from top management and several interrelated factors.

Research limitations/implications – The main limitations of the study are that the research is cross-sectional in nature and regional in focus. Namely, the data used to validate the structural model were gathered from a small representative subset of the study population – i.e. Mexican public HEIs – and at a specific point in time.

Practical implications – The results reported here represent a reference framework for HEIs worldwide that wish to continuously improve their processes through LSS improvement projects.

The authors thank the National Council of Science and Technology (CONACYT), Mexico, for their support in developing this work.

Disclosure statement: The authors declare no potential conflicts of interest with respect to the publication of this research.

International Journal of Lean Six Sigma
© Emerald Publishing Limited
2040-4166
DOI 10.1108/IJLSS-03-2021-0047

Originality/value – This study proposes a statistically validated model using the SEM technique that depicts the relationships among LSS CSFs in HEIs.

Keywords Higher education, Improvement projects, Lean six sigma, Structural equation modeling

Paper type Research paper

1. Introduction

Higher education institutions (HEIs) are organizations providing postsecondary or third-level education. Over the years, higher education has played a key role in the social, economic and political development of countries(Ah-Teck and Starr, 2013); however, nowadays, HEIs face great challenges as a result of globalization, international competitiveness, reforms and restrictions in government funds (Alshubiri, 2021). All of these factors demonstrate that there is a latent need to improve the quality of services offered in universities and colleges (Kolar *et al.*, 2018).

HEIs have been continuously striving for higher quality under the constant pressure of public scrutiny, tight budgets and cuts in private, state and federal funding (Bandyopadhyay and Lichtman, 2007). Additionally, HEIs require innovative quality systems to improve their fundamental administrative processes and services. In this sense, lean six sigma (LSS) is a methodology for continuous quality improvement that aims to eliminate waste and reduce variation in any type of process; LSS is necessary because organizations and people need a methodology to improve and solve problems since the processes do not improve by themselves. In fact, if they are not periodically improved, processes deteriorate over time (Snee, 2010). As a management philosophy, LSS is suitable for any organization, including HEIs, and offers a wide range of quality-related benefits (Antony *et al.*, 2018; Hess and Benjamin, 2015; Isa and Usmen, 2015; Oko and Kang, 2015) and according to Cudney *et al.* (2020), the introduction and implementation of this strategy may improve the quality of higher education and add value that continuously enhances the customer (student) satisfaction.

HEIs around the world embark on LSS projects to increase the quality of their services by reducing waste and costs, thus increasing market share and improving process performance. The success of any LSS project is bound to a series of elements, commonly referred to as critical success factors (CSFs). If the objectives of an LSS project are not aligned with these factors, the project is most likely destined to fail (Rockart, 1979). The CSFs for LSS implementation systematically highlight the key areas that should be carefully considered by HEIs to attain the expected performance goals. By understanding these CSFs, colleges and universities can successfully identify the issues that adversely affect their processes to subsequently avoid or reduce the occurrence of any factors leading to such issues (Alkarney and Albraithen, 2018). In addition, CSFs may address the challenges associated with LSS implementation that Cudney *et al.* (2020) describe in their research.

The novelty of the present work is to propose a statistically validated model using the SEM technique that depicts the theoretical relationships among LSS CSFs in HEIs, to support these organizations in achieving the desired results in their processes by realizing improvement projects within the LSS philosophy. Hair *et al.* (2014) stated that perhaps the strongest type of theoretical inference a researcher can draw is a causal inference, which involves the proposition that a dependence relationship is actually based on causation. A causal inference involves a hypothesized cause-and-effect relationship. If we understand the causal sequence between variables, then we can explain how a certain cause determines a given effect. So, in this case, through our proposed causal model, top management (TM) can better understand how these CSFs interact, and this knowledge can help the institution to obtain the desired results. Thus, if some organizations have failed to implement this strategy (Antony *et al.*, 2019), our results could provide these institutions with some insights to restructure the implementation strategy they are following.

1.1 Research gap

Although multiple studies have successfully managed to model LSS implementation for different purposes in higher education contexts (Sunder and Antony, 2018; Tetteh, 2018), a statistically validated model that comprehensibly establishes the relationships among CSFs for successful LSS implementation in HEIs has not yet been proposed. As such, in this study, a set of theoretical relationships between the CSFs of LSS is first proposed after an extensive literature review to define the hypotheses that are later statistically validated through a structural model; this model numerically presents how CSFs interact in LSS projects at HEIs, and how the correct approach to such CSFs can help universities and colleges to reach their goals. Thus, taking the aforementioned as a reference, the contribution of our study is to provide new insights on continuous improvement in HEIs by providing a model that depicts the theoretical relationships between CSFs and the benefits of LSS, which will undoubtedly represent relevant information for HEIs staff that are interested in developing improvement projects under the LSS methodology. Thus, with the intention of resolving this research gap, data were collected to test certain theoretical relationships through a structural model addressing the following research questions:

RQ1. What are the causal relationships that arise between LSS CSFs in HEIs?

RQ2. What is the effect of CSFs on LSS benefits in HEIs?

2. Literature review and hypotheses

One of the first studies that proposed LSS implementation in HEIs was conducted by Antony *et al.* (2012). The researchers critically evaluated whether LSS could be an improvement methodology for HEIs. Then, two years later, Antony (2014) identified the factors required for the successful introduction and development of an LSS initiative in the higher education sector. LSS can be applied to facilitate process improvements in curriculum delivery, commercial and auxiliary services, admissions and registration management and research. While there are obstacles to the implementation of LSS, the resulting process improvements and cultural changes (CCs) are worthwhile and notable (Hess and Benjamin, 2015). A study conducted by Sunder (2016) identified the key attributes of the higher education system, which should be understood to instill excellence and quality. The study also provided an idea of the possible application of LSS and the benefits that it can bring to HEIs.

In previous research, a conceptual framework of LSS leadership was proposed, which sets the grounds for testing LSS leadership representations in HEIs. The results suggested that LSS leadership has advantages for HEIs to overcome current problems and challenges (Lu *et al.*, 2017). Additionally, Sunder and Mahalingam (2018) conducted an empirical validation of LSS implementation in HEIs and highlighted the practical challenges and benefits of LSS in educational environments. Antony *et al.* (2018) explored the fundamental challenges and CSFs of an LSS initiative in a British university. Ultimately, the authors found a clear lack of support and commitment from senior management to the sustainability of LSS projects. In this regard, the authors argued that the university seemed to not understand the benefits of LSS in the educational sector, nor was it familiar with LSS tools that can help to solve effectiveness and efficiency problems in processes.

Sunder and Antony (2018) discussed the implementation of LSS in higher education services and suggested a conceptual framework for LSS implementation in HEI contexts with six main stages: LSS readiness, establishing a need through leadership, developing a strategy, educating with the right skill set, team formation, identifying and initiating the LSS project and finally, reviewing and closure. Similarly, Haerizadeh and Sunder (2019) demonstrated the ability of LSS to improve the educational system at a university in Iran, improving student satisfaction levels and the overall grade by 10%; they also reduced wait times for communication with students by 15% and increased tuition by 5%. Finally, Li *et al.* (2019) introduced a case study in which LSS was implemented to improve the service process in an HEI, finding that the service process contained a large component of human behavior, which dramatically increases the unpredictability and complexity of the entire service delivery and makes it difficult for improvement teams to identify the root cause of the problem. The following paragraphs thoroughly discuss such CSFs and present our research hypotheses.

According to Henderson and Evans (2000) and Laosirihongthong *et al.* (2006), TM must demonstrate leadership and commitment as organizations and institutions embark on new improvement projects. Moreover, TM involvement and commitment must be perceived through actions such as organizational restructuring, promoting CC among employees and financial support. Without a commitment from managers and top administrators, any LSS project plan is a waste of energy and time (Antony *et al.*, 2012). As researchers have pointed out, improvement strategies under the LSS philosophy should not consist of isolated actions. They must be linked with organizational strategies and priorities, which, in turn, must aim at improving customer satisfaction and fulfilling financial and operational goals (Antony *et al.*, 2012; Cheng, 2013; Pande *et al.*, 2000). Similarly, as Antony *et al.* (2012) claim, HEIs leaders must establish a clear vision of the direction of the LSS projects. It is also essential to ensure that each LSS project is properly aligned with the institution's strategic goals to finally recognize and reinforce successful improvements. Näslund (2013) and Sunder and Antony (2018) also support the claim that improvement strategies and decisions are bound to senior management commitment. García-Alcaraz *et al.* (2018) mentioned that managerial commitment is required to design an implementation strategy. Similarly, Ali *et al.* (2020) mentioned that TMs are those who can integrate LSS in their organizations and create strategies to successfully implement this methodology. That is, a quality-driven organizational culture and mindset for excellence must start from senior management and cascade down the organization so that every level experiences them. Finally, in their study, Laureani and Antony (2012), as key findings highlighted that TM and LI are two of the most important factors for the effective implementation of LSS. Following this discussion, we propose the first research hypothesis as follows:

> *H1*. TM has a positive effect on Link LSS with institutional strategy (LI) for implementing LSS in HEIs.

Successful CC is led by communication, motivation and quality education (Antony and Banuelas, 2002; Harry and Schroeder, 2000). According to Antony *et al.* (2012), an organizational culture evidences employee behavior and helps organizations identify the strategies that can be managed to support organizational goals. Multiple HEIs, especially community colleges and private universities, use the principles of continuous quality improvement to guide their quality cultures (Holmes *et al.*, 2015). In this sense, the institution's strategy should be to promote LSS as a culture of continuous improvement since its advantage is in the synergy between promoting CC (that is, changing the way of working by changing processes) and educating people in new ways of understanding processes and solving problems (Antony *et al.*, 2012). Finally, while the institution's strategy of LSS implementation is not free of obstacles and challenges, it can serve as an agent of CC for public and private institutions (Hess and Benjamin, 2015). From this perspective, our second research hypothesis is as follows:

H2. LI has a positive effect on CC for implementing LSS in HEIs.

According to Pande *et al.* (2000), multifunctional project and management teams function as a force that breaks down barriers between groups. Team members and teamwork (TW) should be selected based on their skills, such as analytical thinking and knowledge transfer (Delgado *et al.*, 2010). Additionally, according to Antony (2014), the most talented employees should be strategically assigned to projects that provide measurable and quantifiable results. On the other hand, Antony *et al.* (2018) claimed that when embarking on improvement projects, employees and all relevant staff need to be made explicitly aware of not only the purpose of the initiative but also how will the initiative be beneficial and how it will change daily work. In this sense, our third research hypothesis is as follows:

H3. LI has a positive effect on TW for implementing LSS in HEIs.

Link LSS with human resources (HR) helps organizations to promote the desired attitudes among employees and attain the desired goals. If HEIs perceive the achievements of improvement projects as both a performance measure and an opportunity for rewarding employees, successful completion of such projects will follow (Henderson and Evans, 2000; Jeyaraman and Teo, 2010). The power of LSS to create a culture of continuous improvement lies in its ability to change the way work is done through changing processes, as well as in educating people in new ways of understanding processes and solving problems (Antony *et al.*, 2018). As pointed out by Zu *et al.* (2010), by developing a group culture, organizations can promote participation, trust and concern for human development as their fundamental values. Finally, as Szeto and Tsang (2005) claimed, employee training allows organizations to set new goals and prepares employees to think differently, try new things and participate in new behaviors. The fourth hypothesis of this research is proposed as follows:

H4. CC has a positive effect on HR for implementing LSS in HEIs.

TW refers to the collaboration between all involved and the creation of multifunctional teams to solve problems (Lloréns-Montes and Molina, 2006). Chakrabarty and Tan (2007) and Singh and Rathi (2019) stated that the use of LSS in organizations enhances TW among all involved. They also stated that TW improves employee job satisfaction. Therefore, it is of utmost importance for companies to use the skills of all employees and get people from various departments to work as a team in any problem-solving initiative. Echoing Ahmed and Idris (2020), it is important to highlight that staff must be recognized for their contribution and must feel part of the organization. In addition, it is important to mention that an organization is a system of highly interdependent parts; that is, TW is the main axis in continuous improvement. Thus, our fifth hypothesis is as follows:

H5. TW has a positive effect on HR for implementing LSS in HEIs.

According to Antony *et al.* (2012), one of the most important requirements is to develop human capital by providing education and training (ET) to employees. These employees must be equipped with project management tools, a set of process improvement tools and change management tools. On the other hand, Hanaysha (2015) indicated that teams in organizations are usually made up of employees who acquire the necessary skills to achieve desired objectives. In this sense, all team members have the opportunity to teach each other how to perform a particular task with skill and professionalism. TW allows people to help each other, improve their individual skills and get positive feedback without any conflict. In addition to this, Taghizadegan (2006) mentioned that it would be very difficult to achieve improvement-based objectives without TW and adequate training of the entire organization. Finally, according to Antony (2014), one of the main implications of the LSS is that organizations must select and train the right people to execute projects at all levels throughout the institution. In this sense, our sixth research hypothesis states as follows:

H6. TW has a positive effect on ET for implementing LSS in HEIs.

According to Boyd and Gessner (2013), employees must participate as coauthors in the design phase of the measurement system. Employee participation at this stage will promote goodwill and give workers greater authority and control, as well as a genuine interest in the system. On the other hand, Jenicke *et al.* (2008) mentioned that when projects are developed under quantitative and measurable objectives, the results can be used as indicators to evaluate the success of the projects and their benefits. Finally, Hietschold *et al.* (2014) claimed the relevance of human resource management by associating it with organizational performance. Following this discussion, the seventh research hypothesis states as follows:

H7. HR has a positive effect on Clear Performance Metrics (CM) for implementing LSS in HEIs.

Employee ET are pillars of human capital development in organizations (Antony *et al.*, 2012). Likewise, establishing goals that are measurable and quantifiable makes it easier for HEIs to both assess the magnitude of improvements and offer rewards to their employees (Jenicke *et al.*, 2008). From a similar perspective, Sunder (2014) highlighted that having an information system creates a culture of measurement and helps to understand future areas in which to collect data and select problems for continuous improvement. Finally, Bhat *et al.* (2020) stated that data-based validation and solid inferences require reliable data, which is a problem faced by some organizations. In addition, they mention that the problem can be overcome by training all team members on the data collection and validation methodology before the beginning of each phase of the improvement methodology. This approach, along with the brainstorming method, helps the team to customize their data collection plan according to the requirements of each organization. In this sense, our eighth research hypothesis can be stated as follows:

H8. ET has a positive effect on CM for implementing LSS in HEIs.

The benefits of LSS (B) are an important factor since they are associated with a positive action or outcome that favors people and organizations. The benefits of LSS implementation revolve around quality and productivity. These could be academic benefits (Gupta *et al.*, 2020), organizational benefits and customer benefits (Haerizadeh and Sunder, 2019). In educational contexts, research has found that long-term strategic objectives reflect the ability of a HEI to promote itself, maintain sufficient financial resources, recruit and retain high performing students and maintain a professionally qualified faculty staff (Jenicke *et al.*, 2008), which ultimately are all performance metrics. For Antony (2014), LSS performance metrics are set to demonstrate to stakeholders the results and benefits from using their resources. Similarly, Yadav and Desai (2017) mention that proper data collection and analysis assure quality. Following this discussion on the importance of effective communication among HEI departments and LSS project monitoring, our ninth research hypothesis is therefore formulated:

H9. CM has a positive effect on B for implementing LSS in HEIs.

Figure 1 illustrates our conceptual model, which shows the hypothetical structural relationships among the CSFs for LSS implementation and the LSS benefits in HEIs. In the following sections, this model will be statistically validated.

3. Methodology

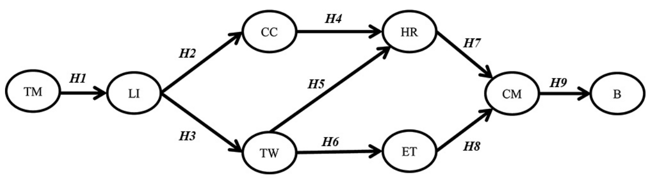
This section describes the stages followed to achieve the research goal. In Figure 2, we present a flow chart that summarizes the steps of the methodology used in the present study, which was adopted by Hair *et al.* (2014).

3.1 Ethics statement

We designed the survey instrument on an electronic platform and allowed the participants to remain anonymous. The first page of the survey requested participants' consent for their participation, specifying that all responses would be voluntary and remain anonymous. The research conforms to the provisions of the Declaration of Helsinki (World Medical Association, 2021), and all ethical guidelines were followed as required for conducting human research, including adherence to the legal requirements of Mexico. This procedure was approved by the Head of the Faculty of Engineering, Architecture and Design of the Autonomous University of Baja California (UABC, by its Spanish acronym).

3.2 Survey development

As a research instrument, our questionnaire allows collecting the necessary information to test and validate the LSS implementation model. Questionnaires aim at measuring constructs, which are unobservable or latent concepts that can be defined in conceptual terms but cannot be directly measured. Similarly, Ben Ruben *et al.* (2020) mentioned that to obtain the inputs for each latent variable, some indicators have to be converted into the form of a questionnaire to ensure that each indicator is assigned with a quantifiable input. The constructs measured in our questionnaire corresponded to the CSFs for LSS implementation identified after a literature review and discussed in the previous section. Each CSF was operationalized through a series of five-point Likert items, taking into account multiple references (Antony, 2014; Cudney *et al.*, 2014; Desai *et al.*, 2012; Habidin and Yusof, 2013; Hess and Benjamin, 2015; Ho *et al.*, 2008; Holmes *et al.*, 2015; Isa and Usmen, 2015; Jeyaraman and Teo, 2010; Laosirihongthong *et al.*, 2006; Lu *et al.*, 2017; Oko and Kang, 2015; Ray *et al.*, 2012; Sunder, 2016; Yi-zhong *et al.*, 2008). The Likert scale can be found in the vast majority of previous factor studies, probably due to its inherent nature of measuring attitude values. The survey's five-point Likert scale format is as follows: never (1), rarely (2),



Source: Authors' own creation

Figure 1. Theoretical model representing the structural relationships among LSS CSFs and benefits in HEIs

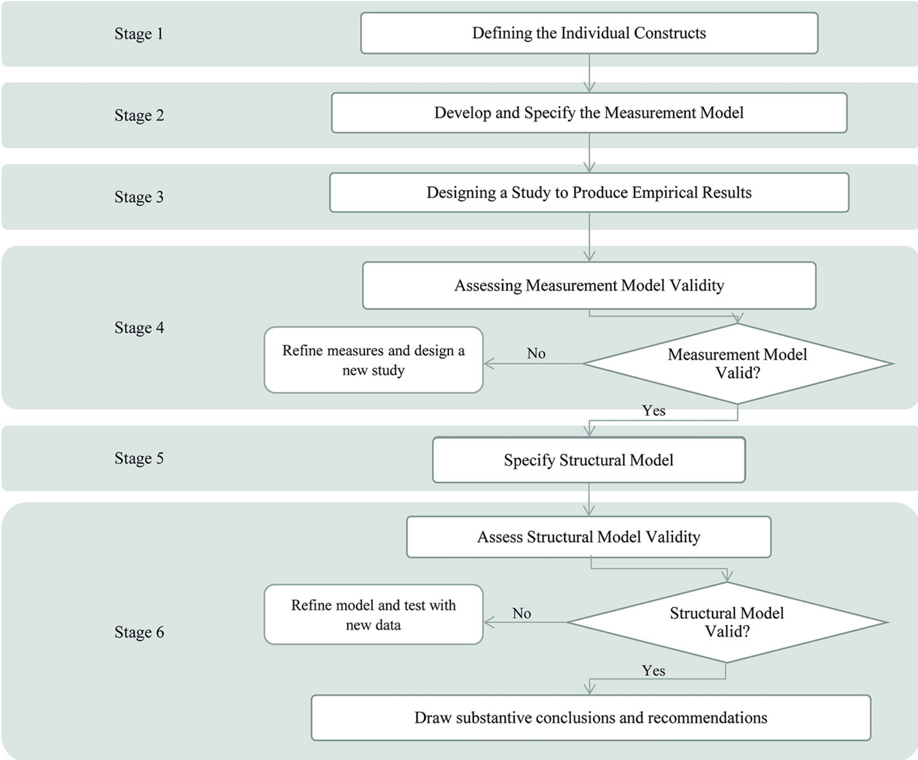


Figure 2. Flow chart representing the steps of the methodology

Source: Authors' own creation

sometimes (3), frequently (4) and always (5). The items corresponding to the TM factor are shown below as an example.

TM of the Academic Unit:

- TM1: Supports and actively participates in quality improvement activities (training, project selection, review and evaluation of phase results).
- TM2: Has built an environment for learning, innovation and decision-making power.
- TM3: Assumes responsibility for the operation of the project
- TM4: Participates in the selection of team members based on the competencies of the staff.
- TM5: Encourages the participation of staff at all levels in the implementation of improvement projects
- TM6: Provides adequate budget and resources for the improvement project.

The final version of the instrument comprises five sections. The first three sections, respectively, introduce the survey, request sociodemographic data of the HEIs and provide a summary on quality improvement tools. Next, the fourth section requests information on the CSFs for LSS implementation. Finally, the fifth section aims to collect data regarding the benefits from LSS projects. This survey was validated in the study of Maciel-Monteon *et al.* (2020), where the operationalization of the constructs was carried out first, followed by some tests to later apply the survey and build the database. Finally, construct validation was carried out through discriminant, convergent and nomological validation. In doing so, it was ensured that each item really represents the theoretical latent variable it is designed to measure.

3.3 Sampling

We administered the questionnaire in Mexican public HEIs. According to the Secretariat of Public Education (SEP, by its Spanish acronym), public universities and colleges in Mexico account for more than 70% of total domestic enrollment in higher education (SEP, 2018). In Mexico, there are just over 600 public HEIs, with around 1,800 academic units. As the population is finite and known, the procedure to be followed was derived from Spiegel and Stephens (2009); hence, using a confidence level of 95% and an estimation error (ε) equal to 0.05, it was necessary to survey 317 academic units as a representative sample of the target population. Based on simple random sampling, we collected more than 700 responses from just over 400 different academic units, and thus the suggested sample size was met, with a response rate of approximately 24%. Quality system coordinators and academic staff experienced in conducting improvement projects were the target personnel surveying after ensuring that they received training to execute and monitor the improvement projects. Initially, the questionnaire was sent to HEIs in the northwest of Mexico to carry out a pilot test. These responses were used to make some modifications to the questionnaire. After this, the survey was sent electronically to the rest of the country. In addition, to increase the response rate, it was necessary to contact some HEIs by telephone and visit some directly.

3.4 Data capture and screening

According to Hair *et al.* (2014 and Kline (2016), ensuring that the collected data are clean before conducting further statistical analyses guarantees that such information is reliable and valid for testing causality. Data screening usually involves conducting a series of tests to check for outliers, univariate normality, multivariate normality and multicollinearity. We used the Mahalanobis distance ($p < 0.001$) to find outliers in our data (Kline, 2016), removing 203 surveys as a result.

To check for univariate normality, we computed kurtosis and skewness indices. For normality, kurtosis values within a range of $\pm$ 3 are required (Decarlo, 1997), while skewness values within a range of $\pm$ 2 are also needed (Curran *et al.*, 1996). This assumption was fulfilled since our results revealed kurtosis values between -0.60 and 1.18 and skewness values between -1.20 and -0.29. On the other hand, we checked for multivariate normality by computing Mardia's coefficient of kurtosis (Mardia, 1970, 1974) on SPSS Amos, which according to Khine (2013), values lower than p (p + 2), where p stands for the number of observable variables in the model are evidence of multivariate normality of data. Once more, this assumption was not violated since results revealed a multivariate kurtosis of 252.2, much lower than p (p + 2) = 2,499. Finally, multicollinearity was also tested by computing both the correlation and the variance inflation factors (VIF) indices. Usually, a correlation coefficient lower than 0.85 (Khine, 2013) and VIF values lower than 10 are accurate indicators of the absence of multicollinearity problems (Kline, 2016). Again, this assumption was not violated since the maximum VIF and correlation index values were 6.25 and 0.81, respectively.

Furthermore, in the present study, we performed a test to verify the multigroup invariance. This analysis was carried out in two stages – in the measurement model and the structural model. The first step was to divide the database into two groups, the first half made up of the first responders to the survey and the second half containing the late responders. The confirmatory factor analysis (CFA) was performed with the two groups, and the findings were consistent. All factor loadings were similar and significant ($p < 0.01$), which suggests that the model presented good configurational invariance. Then, the $\chi 2$ statistic and comparative fit index (CFI) were verified; thus, the $\chi 2$ value was statistically significant in both groups, and the difference between the CFI indices was 0.0058, which meets the criteria mentioned by Byrne (2016). According to Byrne (2016), once the equivalence of the measurement model has been established, the next step is to test the invariance related to the structural model. The same comparisons were also performed via SEM models with satisfactory results.

3.5 Exploratory factor analysis

To determine the feasibility of exploratory factor analysis, we calculated the Kaiser–Meyer–Olkin (KMO) index and performed Bartlett's Test of Sphericity (BTS) to the complete data matrix. According to Kaiser and Rice (1974), KMO values higher than 0.9 and BTS statistically significant are reliable indicators of the feasibility to conduct factor analysis. In this research, the KMO value was 0.982 and BTS was significant ($p < 0.01$). Finally, the factor analysis consolidated eight constructs with eigenvalues greater than 1 using 49 variables with significant factors loadings.

3.6 Confirmatory factor analysis

We relied on CFA to provide a confirmatory test of our measurement theory. A measurement theory specifies how measured variables logically and systematically represent constructs involved in a theoretical model. A successfully validated model shows both acceptable levels of goodness of fit (GOF) and satisfactory evidence of construct validity. The values of any GOF are the result of a mathematical comparison between the estimated covariance matrix (theory) and the observed covariance matrix (reality). The closer the values of these two matrices are, the better the model is said to fit (Hair *et al.*, 2014). According to Hair *et al.* (2014) and Kline (2016), using three to four GOF indices provides adequate evidence of model fit. It is necessary to report at least one incremental index and one absolute index in addition to the $\chi 2$ statistic. The most common GOF indices include $\chi 2$ statistics, the root mean square error of approximation (RMSEA) and the CFI or the Tucker–Lewis index (TLI). All these metrics were computed using SPSS Amos 23. It is important to highlight that, in our proposed model, all the latent constructs are predicted to be reflective. That is, the direction of causality goes from the latent construct to a measured variable (items).

3.6.1 Construct validity. Construct validity measures the degree to which a set of measured variables actually represent the latent theoretical construct that they are designed to measure. It is determined by both convergent and discriminant validity (Hair *et al.*, 2014). On the one hand, convergent validity measures the degree to which the different items measure the same concept (Khan and Naeem, 2018), and it is estimated through average variance extracted (AVE), with 0.5 as the minimum threshold (Hair *et al.*, 2014). On the other hand, discriminant validity measures whether one construct is different from another (Kharub and Sharma, 2018). To this end, as Fornell and Larcker (1981) propose, we compare the square root of the AVE values and the corresponding correlation between any pair of latent constructs.

	%
Position held within the academic unit	
Administrator	6
Quality system coordinator	17
Executive	12
Chief or coordinator	33
Professor	20
Other	12
Length of service	
Less than 2 years	30
2 to 5 years	30
From 5 to 10 years	22
Higher than 10 years	18
Gender of the respondent	
Male	56
Female	44

Source: Authors' own creation

Table 1. Demographic details

3.7 Model evaluation and hypothesis testing

As a statistical technique, SEM adopts a CFA approach to analyze both the structural relationships between two latent variables (Byrne, 2016) and relationships among multiple variables (Khan and Naeem, 2018). The theoretical SEM model depicted in Figure 1 was tested on SPSS Amos 23.

4. Results

With regard to the demographic data from the surveyed population (Table 1), some relevant aspects can be observed, such as the percentages regarding the position, length of service and gender of the respondents. It is important to mention that 100% of the respondents stated that they had participated in improvement projects within their HEIs. In addition, the respondents stated that they had knowledge of improvement methodologies, such as LSS and ISO 9001. Regarding the position held by the surveyed personnel, the HEI personnel with the highest participation level were the chiefs or coordinators and professors of the different academic units. It is worth mentioning that the "others" category contains responses from different profiles, such as deputy directors, administrative assistants and library managers.

GOF indices	Recommended values	Measurement model	Research model and hypotheses
χ^2/df	3 or less (Bollen, 1989)	2.49	2.88
CFI	Greater than 0.90 (Hair *et al.*, 2014; Schumacker and Lomax, 2016)	0.9522	0.9393
TLI	Greater than 0.90 (Hair *et al.*, 2014; Schumacker and Lomax, 2016)	0.9478	0.9352
RMSEA	Less than 0.08 (Browne and Cudeck, 1993)	0.0517	0.0582

Source: Authors' own creation

Table 2. Goodness of fit estimates

Table 3. Results of discriminant validity analysis

Construct	Benefits of LSS (B)	Cultural change (CC)	Top management involvement and commitment (TM)	Education and training (ET)	Link LSS with institutional strategy (LI)	Team members and teamwork (TW)	Clear performance metrics (CM)	Link LSS with human resources (HR)
Benefits of LSS	0.6799[a]	0.4869	0.5323	0.5034	0.6029	0.6013	0.6490	0.6345
Cultural change	0.6978	0.6228[a]	0.4952	0.4364	0.5306	0.4742	0.5216	0.4876
Top management involvement and commitment	0.7296	0.7037	0.7312[a]	0.5745	0.6691	0.5813	0.5344	0.5572
Education and training	0.7095	0.6606	0.7580	0.6989[a]	0.6586	0.6278	0.6482	0.6264
Link LSS with institutional strategy	0.7765	0.7284	0.8180	0.8116	0.7614[a]	0.7089	0.7412	0.6986
Team members and teamwork	0.7755	0.6886	0.7624	0.7923	0.8420	0.7701[a]	0.7508	0.7102
Clear performance metrics	0.8056	0.7222	0.7310	0.8051	0.8609	0.8665	0.8000[a]	0.7380
Link LSS with human resources	0.7965	0.6983	0.7465	0.7915	0.8358	0.8428	0.8590	0.7393[a]

Notes: [a]AVE values; values below the diagonal are correlations between constructs; values above the diagonal are squared correlations between constructs
Source: Authors' own creation

4.1 Data validation

Table 2 lists the GOF indices estimated for the model. As previously mentioned, these indices are the most frequently reported in the literature, and all of them showed acceptable values.

As in Hair *et al.* (2014), we considered items with factor loadings higher than 0.5, but preferably equal to 0.7, as significant for construct validity. In this sense, all items had a factor loading higher than the threshold, with B1 being the item with the lowest factor loading (0.6448). Regarding AVE values, Table 3 shows that all constructs had an acceptable value (higher than 0.5). Hence, we concluded that all of the constructs from the theoretical model have enough convergent validity. Regarding internal consistency, the value of Cronbach's alpha index was greater than 0.7 – the cutoff recommended by George and Mallery (2016) – in all of the constructs. This demonstrated that our survey instrument had internal consistency. Additionally, the results listed in Table 3 also demonstrate that the latent variables had discriminant validity because the AVE values were greater than the squared correlation between factors indicating that the constructs are independent of one another. To ensure discriminant validity among constructs, some items were removed.

4.2 Assessing the structural model

According to Hair *et al.* (2014) and Kline (2016), to evaluate a structural model fit, the most important indices are the $\chi 2$ statistic, the CFI or TLI and the RMSEA since they will generally provide enough and unique information to this end. These indices are presented in Table 2 and suggest the model provides a good overall fit. Table 4 lists the results of the SEM analysis, showing standardized regression weights, standard error, the critical ratio (CR) and the significance value (p). As regard CR, Kline (2016) recommend absolute values higher than 1.96, whereas our results exhibit values ranging from 3.66 to 23.68, thus indicating that the structural parameter estimates were highly significant for the nine research hypotheses.

Path analysis procedures provide estimates for each relationship (arrow) in a structural model; the estimates can be used as regression coefficients to estimate the values of any construct in the model. The sizes of these coefficients indicate the size of the impact that each factor has on another, and this is in accordance with the hypotheses under verification. In addition, when statistical inference tests are applied, the researcher can assess the probability that the estimates are significant (not equal to zero). According to our estimates, the structural model depicted in Figure 3 exhibited acceptable model fit, and the path estimates for the nine hypotheses were significant in the predicted direction.

Hypotheses				S.R.W.	S.E.	C.R.	*P*	Results
H1	TM	→	LI	0.8491	0.0494	18.2747	***	Supported
H2	LI	→	CC	0.7626	0.0366	14.6982	***	Supported
H3	LI	→	TW	0.9146	0.0363	23.6855	***	Supported
H4	CC	→	HR	0.1585	0.0626	3.6649	***	Supported
H5	TW	→	HR	0.7747	0.0560	15.0071	***	Supported
H6	TW	→	ET	0.8583	0.0425	22.4062	***	Supported
H7	HR	→	CM	0.5835	0.0514	10.9708	***	Supported
H8	ET	→	CM	0.3753	0.0466	7.6228	***	Supported
H9	CM	→	B	0.8188	0.0422	17.7189	***	Supported

Note: ***Significant at 0.001 level
Source: Authors' own creation

Table 4. Structural model analysis results

The structural equation model aims to explain how LSS CSFs are interrelated and how LSS has an impact on the performance of improvement projects conducted by public HEIs in Mexico.

5. Discussion

5.1 Theoretical contribution

Sunder and Antony (2018) proposed a model for implementing LSS in HEIs, collecting several CSFs and relating them to benefits gained; however, after a literature review, we propose new factors, such as CC, HR and CM, which are very important to this study, contributing to previous knowledge. So, our study makes an essential contribution to the theory of continuous improvement by analyzing LSS application to HEIs and proposing causal relationships between current reported and news CSFs identified and benefits obtained. These relationships are validated by a structural equation model that proposes the implementation process be begun only after the TM is sufficiently confident that adopting this strategy will benefit the institution. Further, six additional CSFs and their respective relationships are analyzed as mediating factors between TM and the benefits.

Our findings support the structuralist theory since it is demonstrated that everyone within the HEIs has a specific and indispensable role in achieving organizational objectives. Managers must seek a balance between these and all goals of their subordinates. However, our findings also support systems theory since HEIs are open systems that react to their context as the students' and teachers' curricular needs due to skills requirements, changes in educational policy and technological advances in the teaching system.

Furthermore, although this is mostly a methodological contribution, it is important to highlight that prior to this study, no model of LSS CSFs in HEIs using SEM had been reported. This research represents a step forward in the knowledge of the application of LSS in HEIs, since it uses already reported CSFs and identifies new ones, and relates them to the benefits obtained, which is one of the best contributions. The quantification of these relationships between the CSFs and the benefits obtained will allow managers to identify which activities are the most important to achieve specific benefits, which will help them to focus their resources according to their own needs, make better decisions and make better use of their resources.

5.2 Interpretation and discussion of the result

Having successfully validated the constructs and their relationship in the model in the context of HEIs, we proceed to interpret our findings as follows. First, we found that TM involvement and commitment have a positive direct effect on Link LSS with institutional strategy (LI) (0.84) and an indirect effect on the rest of the constructs. Such results are

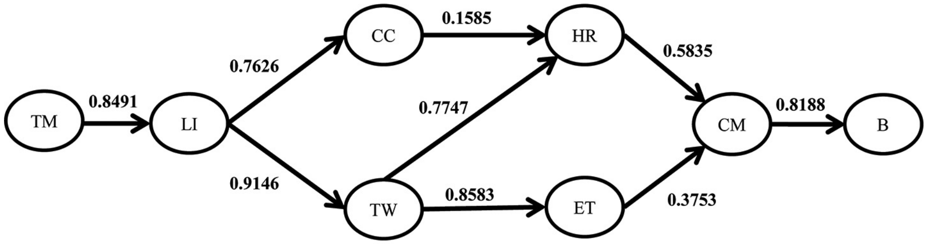


Figure 3. Standardized path coefficients for LSS CSFs in HEIs – structural model

Source: Authors' own creation

consistent with the theory claiming that management commitment is the driving force and the greatest enabler of quality improvement in HEIs, as mentioned by the Malcolm Baldrige National Quality Award, the European Quality Award and the Deming Prize (Djordjevic *et al.*, 2018; Suresh *et al.*, 2012). Active management leadership defines the goals of an improvement strategy, ensures such goals are properly aligned with the institutional strategy and defines LSS project group members.

Likewise, LI has a positive direct effect on both Team members and TW and CC. First, the strong relationship between LI and TW (0.91) can be explained by the fact that senior management in HEIs consolidates multidisciplinary improvement project teams (Antony, 2014) only after making sure that the goals of an improvement project are clearly aligned with the institution's organizational strategy (Antony, 2014). The effect of LI on CC is slightly less strong (0.76), and it is then followed by the effect of CC on Link LSS with HR (0.15). Likewise, TW presented a significant effect on both HR (0.77) and ET (0.85). Such results are consistent with the claims in Antony and Banuelas (2002), Dubey *et al.* (2016), Kwak and Anbari (2006), Sunder and Antony (2018) and Szeto and Tsang (2005) that TM sets the goals and vision of an improvement project, defines the strategies necessary to attain such goals and clearly communicates such information to all staff members. In a recent study, Sunder and Antony (2020) coincide with the aforementioned its authors emphasize the importance of leadership for the sustainability of LSS and that the senior management of HEIs must ensure that the LSS is an improvement strategy that continues to be part of the university strategy.

Besides, according to our model, HR has a direct effect on CM (0.58); this result is consistent with Boyd and Gessner (2013) since they mention that employee participation is important for the measurement system and even according to Singh and Rathi (2019), some metrics to be developed are related to HR metrics since they add value by clarifying various information required to make solid decisions about talent. On the other hand, a significant direct effect of ET on CM (0.37) was also verified; this is similar to that mentioned by Bhat *et al.* (2020) that all members of the improvement team must receive training in data collection and validation and certainly, solid training in the definition of correct and clear metrics must be paramount to monitor more precisely how effective the activities and tools applied are being to reach the objectives during the execution of any improvement project.

Metrics and data analysis are essential to the success of LSS since without precise information, any decision-making process relies merely on subjective opinions and intuitions. Moreover, in the context of LSS benefits, data analysis and metrics help to understand whether progress is being made and to what extent, thus allowing organizations to plan accurately and make changes when necessary to attain planned goals under the cycle of continuous improvement. Our structural model exhibits the importance of metrics and data analysis for HEIs, since the highly significant effect of CM on LSS benefits (B) (0.81). Such findings support the research of Sunder and Antony (2018), in which the authors claimed that it is important for organizations to rely on different types of metrics to define success and measure progress.

All of the CSFs integrated in the structural model contribute, either directly or indirectly, to obtaining the expected benefits of LSS projects. Overall, our findings indicate that LSS benefits for HEIs can be divided into academic benefits, organizational benefits and customer benefits. Academic benefits comprise increased student academic performance and better exam results. In their research, Gupta *et al.* (2020) mentioned similar results regarding academic benefits and demonstrated that the LSS methodology can be a viable approach to reduce school dropout in HEIs. On the other hand, organizational benefits refer to financial benefits, infrastructure and equipment improvement, increased TW and datadriven decision-making. Benefits for internal customers, such as HEI staff, include increased satisfaction at work, better quality of services and processes, quality certifications across academic programs and better positioning. This coincides with what was reported by Haerizadeh and Sunder (2019), who managed to obtain benefits such as increasing student satisfaction and reduced waiting times, which confirms the applicability of LSS in HEIs. In turn, such benefits have a positive impact on external customers such as parents, employers and society in general.

The structural equation model proposed in this research quantifies the causal relationships among the CSFs for LSS implementation in Mexican public HEIs and explains how such CSFs have an impact on the benefits obtained from LSS improvement projects. Characterizing and understanding the relationships among CSFs for LSS allows Mexican public HEIs to focus their efforts and resources on those factors that are more beneficial. Until now, a statistically-validated model that comprehensibly establishes the relationships among CSFs for successful LSS implementation in HEIs had not yet been proposed.

6. Conclusion

Studies about LSS in HEIs have been growing in the past decade; in the area of academic research, a foreseeable future would include an increase in the cases of applications of this methodology to HEIs, since it has been repeatedly demonstrated that it is feasible and that with it, it is possible to obtain diverse benefits for all stakeholders involved in such improvement projects carried out following the LSS guidelines. The present study could be of help to increase the chances of a successful implementation of LSS in HEIs. The main goal of this research was to identify and statistically validate the relationships among CSFs for LSS implementation and the impact of such factors on the benefits of LSS projects. After an extensive review of the literature and following the validation and testing of the model, we found an overall significant positive relationship between CFSs for LSS and LSS benefits. Our results support the conclusion that any improvement initiative begins with proper TM involvement and commitment and is followed by a series of LSS implementation facilitators, of which link LSS with institutional strategy (LI) stands out. In turn, after HEIs align the goals of an improvement project with their organizational goals, mediating factors such as cultural CC and team members and TW function as a link between link LSS with HR and ET, which is ultimately monitored and reviewed through clear performance metrics. Additionally, we found that the main benefits of LSS in HEIs revolve around educational processes and student performance.

To propose the structural model, we first conducted an extensive literature review to define the CSFs for LSS in higher education. Then, we developed a survey instrument to collect information on LSS implementation and benefits in Mexican public HEIs. The statistical validation of the survey was conducted by gathering data from public universities in Mexico. Then, we proposed the LSS structural equation model based on the reviewed literature and validated it with the collected data. Ultimately, our findings on the structural model support the theoretical model. Therefore, our structural model is an important contribution not only to the literature on LSS implementation in the education sector but also to the literature on cost savings and quality improvement. The SEM technique was used to validate this model, that is, to statistically test the proposed hypotheses that represent the relationships of LSS CFSs in HEIs, which according to our literature review, had not been done previously. This model is intended to serve as a support for decision-makers in these organizations to make better use of available resources for the continuous improvement of various processes by identifying in advance possible obstacles to the implementation of LSS during the planning and execution of improvement projects and also to serve as a reference for the construction of future continuous improvement policies seeking quality and excellence. Additionally, our findings represent a reference framework for HEIs that are interested in developing improvement projects under the LSS methodology to gain a better competitive advantage and better social positioning. Quality in HEIs is thoroughly scrutinized since universities and colleges are committed to the professional, social and humanistic development of their students, who, to some extent, have the responsibility to contribute to better living conditions and welfare in their communities. In fact, this is an urgent world need, especially in developing countries.

7. Limitations and future research

This study is subject to some major limitations, which may suggest future research. First, the study is cross-sectional in nature and regional in focus. Namely, the data used to validate the structural model were gathered from a small representative subset of the study population – i.e. Mexican public HEIs – and at a specific point in time. Hence, as suggestions for future work, it would be suitable to conduct a longitudinal study of the same phenomenon (LSS implementation and benefits in HEIs) to compare the behavior of the relationships between LSS CSFs over time. Second, to change the regional focus, we suggest replicating the study in other geographical contexts and among private HEIs to determine whether cultural factors and context-related factors influence the model results. Finally, it could be interesting to incorporate some new factors and hypothetical relationships into the structural model according to the knowledge or experience of the researchers.

References

Ahmed, A.O. and Idris, A.A. (2020), "Examining the relationship between soft total quality management (TQM) aspects and employees' job satisfaction in 'ISO 9001' Sudanese oil companies", *The TQM Journal*, Vol. 33 No. 1, pp. 95-124. doi: 10.1108/TQM-05-2019-0147.

Ah-Teck, J.C. and Starr, K. (2013), "Principals' perceptions of 'quality' in Mauritian schools using the Baldrige framework", *Journal of Educational Administration*, Vol. 51 No. 5, pp. 680-704, doi: 10.1108/JEA-02-2012-0022.

Ali, Y., Younus, A., Khan, A.U. and Pervez, H. (2020), "Impact of lean, six sigma and environmental sustainability on the performance of SMEs", *International Journal of Productivity and Performance Management*, Vol. 70 No. 8, pp. 2294-2318, doi: 10.1108/IJPPM-11-2019-0528.

Alkarney, W. and Albraithen, M. (2018), "Are critical success factors always valid for any case? A contextual perspective", *IEEE Access*, Vol. 6, pp. 63496-63512.

Alshubiri, F.N. (2021), "Analysis of financial sustainability indicators of higher education institutions on foreign direct investment: empirical evidence in OECD countries", *International Journal of Sustainability in Higher Education*, Vol. 22 No. 1, pp. 77-99.

Antony, J. (2014), "Readiness factors for the lean six sigma journey in the higher education sector", *International Journal of Productivity and Performance Management*, Vol. 63 No. 2, pp. 257-264.

Antony, J. and Banuelas, R. (2002), "Key ingredients for the effective implementation of six sigma program", *Measuring Business Excellence*, Vol. 6 No. 4, pp. 20-27.

Antony, J., Ghadge, A., Ashby, S.A. and Cudney, E.A. (2018), "Lean six sigma journey in a UK higher education institute: a case study", *International Journal of Quality and Reliability Management*, Vol. 35 No. 2, pp. 510-526.

Antony, J., Krishan, N., Cullen, D. and Kumar, M. (2012), "Lean six sigma for higher education institutions (HEIs): challenges, barriers, success factors, tools/techniques", *International Journal of Productivity and Performance Management*, Vol. 61 No. 8, pp. 940-948.

Antony, J., Lizarelli, F.L., Fernandes, M.M., Dempsey, M., Brennan, A. and McFarlane, J. (2019), "A study into the reasons for process improvement project failures: results from a pilot survey", *International Journal of Quality and Reliability Management*, Vol. 36 No. 10, pp. 1699-1720.

Bandyopadhyay, J.K. and Lichtman, R. (2007), "Six sigma approach to quality and productivity improvement in an institution for higher education in the United States", *International Journal of Management*, Vol. 24 No. 4, pp. 802-824.

Ben Ruben, R., Vinodh, S. and Asokan, P. (2020), "Development of structural equation model for lean six sigma system incorporated with sustainability considerations", *International Journal of Lean Six Sigma*, Vol. 11 No. 4, pp. 687-710.

Bhat, S., Gijo, E.V., Rego, A.M. and Bhat, V.S. (2020), "Lean six sigma competitiveness for micro, small and medium enterprises (MSME): an action research in the Indian context", *The TQM Journal*, Vol. 33 No. 2, pp. 379-406.

Bollen, K.A. (1989), *Structural Equations with Latent Variables*, Wiley, New York, NY.

Boyd, N. and Gessner, B. (2013), "Human resource performance metrics: methods and processes that demonstrate you care", edited by Marin Kawamura, K, *Cross Cultural Management: An International Journal*, Vol. 20 No. 2, pp. 251-273, doi: 10.1108/13527601311313508.

Browne, M.W. and Cudeck, R. (1993), "Alternative ways of assessing model fit", in Bollen, K.A. and Long, S.J. (Eds), *Testing Structural Equation Models*, Sage, Newbury Park, CA.

Byrne, B.M. (2016), *Structural Equation Modeling with Amos: Basic Concepts, Applications, and Programming*, 3rd ed., Routledge, New York, NY.

Chakrabarty, A. and Tan, C.K. (2007), "The current state of six sigma application in services", *Managing Service Quality: An International Journal*, Vol. 17 No. 2, pp. 194-208.

Cheng, J. (2013), "Linking six sigma to business strategy: an empirical study in Taiwan", *Measuring Business Excellence*, Vol. 17 No. 1, pp. 22-32.

Cudney, E.A., Elrod, C.C. and Stanley, S.M. (2014), "A systematic literature review of six sigma practices in education", *International Journal of Six Sigma and Competitive Advantage*, Vol. 8 Nos 3/4, pp. 163-175.

Cudney, E.A., Venuthurumilli, S.S.J., Materla, T. and Antony, J. (2020), "Systematic review of lean and six sigma approaches in higher education", *Total Quality Management and Business Excellence*, Vol. 31 Nos 3/4, pp. 231-244.

Curran, P.J., West, S.G. and Finch, J.F. (1996), "The robustness of test statistics to nonnormality and specification error in confirmatory factor analysis", *Psychological Methods*, Vol. 1 No. 1, pp. 16-29.

Decarlo, L.T. (1997), "On the meaning and use of kurtosis", *Psychological Methods*, Vol. 2 No. 3, pp. 292-307.

Delgado, C., Ferreira, M. and Castelo Branco, M. (2010), "The implementation of lean six sigma in financial services organizations", *Journal of Manufacturing Technology Management*, Vol. 21 No. 4, pp. 512-523.

Desai, D.A., Antony, J. and Patel, M.B. (2012), "An assessment of the critical success factors for six sigma implementation in Indian industries", *International Journal of Productivity and Performance Management*, Vol. 61 No. 4, pp. 426-444.

Djordjevic, P., Panic, M., Arsic, S. and Zivkovic, Z. (2018), "Impact of leadership on strategic planning of quality", *Total Quality Management and Business Excellence*, Vol. 31 Nos 5/6, pp. 1-15.

Dubey, R., Gunasekaran, A., Childe, S.J., Fosso Wamba, S. and Papadopoulos, T. (2016), "Enablers of six sigma: contextual framework and its empirical validation", *Total Quality Management and Business Excellence*, Vol. 27 Nos 11/12, pp. 1346-1372.

Fornell, C. and Larcker, D.F. (1981), "Evaluating structural equation models with unobservable variables and measurement error", *Journal of Marketing Research*, Vol. 18 No. 1, pp. 39-50.

García-Alcaraz, J., Alor-Hernández, G., Sánchez-Ramírez, C., Jiménez-Macías, E., Blanco-Fernández, J. and Latorre-Biel, J. (2018), "Mediating role of the six sigma implementation strategy and investment in human resources in economic success and sustainability", *Sustainability*, Vol. 10 No. 6, p. 1828.

George, D. and Mallery, P. (2016), *IBM SPSS Statistics 23 Step by Step: A Simple Guide and Reference*, 14th ed., Routledge, New York, NY.

Gupta, S.K., Antony, J., Lacher, F. and Douglas, J. (2020), "Lean six sigma for reducing student dropouts in higher education – an exploratory study", *Total Quality Management and Business Excellence*, Vol. 31 Nos 1/2, pp. 178-193.

Habidin, N.F. and Yusof, S.M. (2013), "Critical success factors of lean six sigma for the Malaysian automotive industry", *International Journal of Lean Six Sigma*, Vol. 4 No. 1, pp. 60-82.

Haerizadeh, M. and Sunder, M.V. (2019), "Impacts of lean six sigma on improving a higher education system: a case study", *International Journal of Quality and Reliability Management*, Vol. 36 No. 6, pp. 983-998.

Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2014), *Multivariate Data Analysis*, 7th ed., Pearson, Harlow.

Hanaysha, J. (2015), "Testing the effects of employee empowerment, teamwork, and employee training on employee productivity in higher education sector", *International Journal of Learning and Development*, Vol. 6 No. 1, pp. 164-178. doi: 10.5296/ijld.v6i1.9200.

Harry, M.J. and Schroeder, R. (2000), *Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations*, 1st ed., Currency, New York, NY.

Henderson, K.M. and Evans, J.R. (2000), "Successful implementation of six sigma: benchmarking general electric company", *Benchmarking: An International Journal*, Vol. 7 No. 4, pp. 260-282.

Hess, J.D. and Benjamin, B.A. (2015), "Applying lean six sigma within the university: opportunities for process improvement and cultural change", *International Journal of Lean Six Sigma*, Vol. 6 No. 3, pp. 249-262.

Hietschold, N., Reinhardt, R. and Gurtner, S. (2014), "Measuring critical success factors of TQM implementation successfully – a systematic literature review", *International Journal of Production Research*, Vol. 52 No. 21, pp. 6254-6272.

Ho, Y.-C., Chang, O.-C. and Wang, W.-B. (2008), "An empirical study of key success factors for six sigma green belt projects at an Asian MRO company", *Journal of Air Transport Management*, Vol. 14 No. 5, pp. 263-269.

Holmes, M.C., Jenicke, L.O. and Hempel, J.L. (2015), "A framework for six sigma project selection in higher educational institutions, using a weighted scorecard approach", *Quality Assurance in Education*, Vol. 23 No. 1, pp. 30-46.

Isa, M.F.M. and Usmen, M. (2015), "Improving university facilities services using lean six sigma: a case study", *Journal of Facilities Management*, Vol. 13 No. 1, pp. 70-84.

Jenicke, L.O., Kumar, A. and Holmes, M.C. (2008), "A framework for applying six sigma improvement methodology in an academic environment", *The TQM Journal*, Vol. 20 No. 5, pp. 453-462.

Jeyaraman, K. and Teo, L.K. (2010), "A conceptual framework for critical success factors of lean six sigma: implementation on the performance of electronic manufacturing service industry", *International Journal of Lean Six Sigma*, Vol. 1 No. 3, pp. 191-215.

Kaiser, H.F. and Rice, J. (1974), "Little Jiffy, Mark Iv", *Educational and Psychological Measurement*, Vol. 34 No. 1, pp. 111-117.

Khan, B.A. and Naeem, H. (2018), "Measuring the impact of soft and hard quality practices on service innovation and organisational performance", *Total Quality Management and Business Excellence*, Vol. 29 Nos 11/12, pp. 1402-1426.

Kharub, M. and Sharma, R. (2018), "An integrated structural model of QMPs, QMS and firm's performance for competitive positioning in MSMEs", *Total Quality Management and Business Excellence*, Vol. 31 Nos 3/4, pp. 1-30.

Khine, M.S. (2013), *Application of Structural Equation Modeling in Educational Research and Practice*, SensePublishers, Rotterdam.

Kline, R.B. (2016), *Principles and Practice of Structural Equation Modeling*, 4th ed., The Guilford Press, New York, NY.

Kolar, T., Erčulj, V. and Weis, L. (2018), "Multigroup validation of the service quality, customer satisfaction and performance links in higher education", *The Service Industries Journal*, Vol. 39 Nos 13/14, pp. 1-25.

Kwak, Y.H. and Anbari, F.T. (2006), "Benefits, obstacles, and future of six sigma approach", *Technovation*, Vol. 26 No. 5/6, pp. 708-715.

Laosirihongthong, T., Rahman, S.-U. and Saykhun, K. (2006), "Critical success factors of six-sigma implementation: an analytic hierarchy process based study", *International Journal of Innovation and Technology Management*, Vol. 3 No. 3, pp. 303-319.

Laureani, A. and Antony, J. (2012), "Critical success factors for the effective implementation of lean sigma", *International Journal of Lean Six Sigma*, Vol. 3 No. 4, pp. 274-283.

Li, N., Laux, C.M. and Antony, J. (2019), "How to use lean six sigma methodology to improve service process in higher education: a case study", *International Journal of Lean Six Sigma*, Vol. 10 No. 4, pp. 883-908.

Lloréns-Montes, F.J. and Molina, L.M. (2006), "Six sigma and management theory: processes, content and effectiveness", *Total Quality Management and Business Excellence*, Vol. 17 No. 4, pp. 485-506.

Lu, J., Laux, C. and Antony, J. (2017), "Lean six sigma leadership in higher education institutions", *International Journal of Productivity and Performance Management*, Vol. 66 No. 5, pp. 638-650.

Maciel-Monteon, M., Limon-Romero, J., Gastelum-Acosta, C., Tlapa, D., Baez-Lopez, Y. and Solano-Lamphar, H.A. (2020), "Measuring critical success factors for six sigma in higher education institutions: development and validation of a surveying instrument", *IEEE Access*, Vol. 8, pp. 1813-1823.

Mardia, K.V. (1970), "Measures of multivariate skewness and kurtosis with applications", *Biometrika*, Vol. 57 No. 3, pp. 519-530.

Mardia, K.V. (1974), "Applications of some measures of multivariate skewness and kurtosis in testing normality and robustness studies Sankhyā", *The Indian Journal of Statistics, Series B (1960-2002)*, Vol. 36 No. 2, pp. 115-128.

Näslund, D. (2013), "Lean and six sigma – critical success factors revisited", *International Journal of Quality and Service Sciences*, Vol. 5 No. 1, pp. 86-100.

Oko, A. and Kang, P.S. (2015), "Lean six sigma approach to improve the admissions process for a Nigerian HE institute", *International Journal of Scientific and Engineering Research*, Vol. 6 No. 5, pp. 368-378.

Pande, P.S., Neuman, R.P. and Cavanagh, R.R. (2000), *The Six Sigma Way: How GE, Motorola, and Other Top Companies Are Honing Their Performance*, McGraw-Hill, New York, NY.

Ray, S., Das, P. and Bhattacharyay, B.K. (2012), "Success factors characterisation towards six sigma implementation in Indian industries", *International Journal of Six Sigma and Competitive Advantage*, Vol. 7 Nos 2/3/4, p. 181.

Rockart, J.F. (1979), "Chief executives define their own data needs", *Harvard Business Review*, Vol. 57 No. 2, pp. 81-93.

Schumacker, R.E. and Lomax, R.G. (2016), *A Beginner's Guide to Structural Equation Modeling*, 4th ed., Routledge, New York, NY.

SEP (2018), "Sistema educativo de los estados unidos mexicanos, principales cifras 2016-2017", Dirección General de Planeación, Programación y Estadística Educativa Secretaría de Educación Pública, México.

Singh, M. and Rathi, R. (2019), "A structured review of lean six sigma in various industrial sectors", *International Journal of Lean Six Sigma*, Vol. 10 No. 2, pp. 622-664.

Snee, R.D. (2010), "Lean six sigma – getting better all the time", *International Journal of Lean Six Sigma*, Vol. 1 No. 1, pp. 9-29.

Spiegel, M.R. and Stephens, L.J. (2009), *Estadística*, 4th ed., McGraw-Hill, México, D.F.

Sunder, M.V. and Antony, J. (2020), "Lean six sigma roadmap for implementation in higher education sector*", in Antony, J. (Ed.), *Lean Six Sigma in Higher Education*, Emerald Publishing, pp. 161-169.

Sunder, M.V. and Mahalingam, S. (2018), "An empirical investigation of implementing lean six sigma in higher education institutions", *International Journal of Quality and Reliability Management*, Vol. 35 No. 10, pp. 2157-2180.

Sunder, M.V. (2014), "Quality excellence in higher education system through six sigma: student team engagement model", *International Journal of Six Sigma and Competitive Advantage*, Vol. 8 Nos 3/4, p. 247.

Sunder, M.V. (2016), "Constructs of quality in higher education services", *International Journal of Productivity and Performance Management*, Vol. 65 No. 8, pp. 1091-1111.

Sunder, M.V. and Antony, J. (2018), "A conceptual lean six sigma framework for quality excellence in higher education institutions", *International Journal of Quality and Reliability Management*, Vol. 35 No. 4, pp. 857-874.

Suresh, S., Antony, J., Kumar, M. and Douglas, A. (2012), "Six sigma and leadership: some observations and agenda for future research", *The TQM Journal*, Vol. 24 No. 3, pp. 231-247.

Szeto, A.Y.T. and Tsang, A.H.C. (2005), "Antecedents to successful implementation of six sigma", *International Journal of Six Sigma and Competitive Advantage*, Vol. 1 No. 3, p. 307.

Taghizadegan, S. (2006), *Essentials of Lean Six Sigma*, Butterworth-Heinemann, Burlington, MA.

Tetteh, G.A. (2018), "Evaluating university leadership performance using lean six sigma framework", *International Journal of Lean Six Sigma*, Vol. 10 No. 4, pp. 1018-1040, doi: 10.1108/IJLSS-05-2018-0051.

World Medical Association (2021), "WMA – The world medical Association-WMA declaration of Helsinki – ethical principles for medical research involving human subjects", available at: www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/ (accessed 1 February 2021).

Yadav, G. and Desai, T.N. (2017), "Analyzing lean six sigma enablers: a hybrid ISM-fuzzy MICMAC approach", *The TQM Journal*, Vol. 29 No. 3, pp. 488-511.

Yi-Zhong, M., Gang, Y., Li-Lin, W. and Ree, S. (2008), "The critical success factors of six sigma in China manufacturing industry", *Asian Journal on Quality*, Vol. 9 No. 2, pp. 39-56.

Zu, X., Robbins, T.L. and Fredendall, L.D. (2010), "Mapping the critical links between organizational culture and TQM/six sigma practices", *International Journal of Production Economics*, Vol. 123 No. 1, pp. 86-106.

Corresponding author
Jorge Limon-Romero can be contacted at: jorge.limon@uabc.edu.mx