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Role of Human Knowledge and Communication on Operational Benefits Gained from Six Sigma

Jorge L. García-Alcaraz [1,*] [iD]**, Liliana Avelar-Sosa** [1]**, Juan I. Latorre-Biel** [2] [iD]**,**
Emilio Jiménez-Macías [3] [iD] **and Giner Alor-Hernández** [4]

[1]   Department of Industrial Engineering and Manufacturing, Universidad Autónoma de Ciudad Juárez,
     Av. Del Charro 450 Norte, Col. Partido Romero, P.C. 32310 Ciudad Juárez, Mexico; liliana.avelar@uacj.mx
[2]   Department of Mechanical Engineering, Energy and Materials, Universidad de Navarra,
     Avda. de Tarazona s/n, P.C. 31500 Tudela, Spain; juanignacio.latorre@unavarra.es
[3]   Department of Electrical Engineering, Universidad de La Rioja, C/San José de Calasanz 31,
     P.C. 26004 Logroño, Spain; emilio.jimenez@unirioja.es
[4]   Division of Research and Postgraduate Studies, Instituto Tecnológico de Orizaba, Oriente 9,
     Emiliano Zapata Sur, P.C. 94320 Orizaba, Mexico; galor@itorizaba.edu.mx
*   Correspondence: jorge.garcia@uacj.mx; Tel.: +52-656-688-4843

Abstract: Six Sigma (SS) is a production philosophy focused on human experiences and knowledge, aimed to minimize defects of products and services. The appropriate implementation of SS requires an education process, reliable data analysis, efficient didactic material, statistical techniques and human knowledge to improve communication and operational benefits. In this article, we present a structural equation model integrating those aspects as latent variables and relating them with ten hypotheses. Data for hypothesis validation were gathered among 301 manufacturing companies, and assessed using partial least squares (PLS) to estimate direct, indirect, and total effects. As results, we found that access to reliable information, trusted analysis and knowledgeable management are crucial for SS implementation at the problem definition stage. Likewise, to execute and control SS projects, it is important to be trained in statistical techniques through clear didactic materials.

Keywords: training; education; communication; six sigma; structural equation model

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1. Introduction

To stay afloat in this globalized context, companies must adopt and implement tools, techniques, and methods that have helped other companies to succeed. One of the most popular of these methodologies is Six Sigma (SS), which is part of Total Quality Management (TQM). SS has its origins in the 1980s, in the Motorola industry and, due to its success, years later, other companies such as Allied Signal, Bombardier, Siebe, Sony, Polaroid, Toshiba and Texas Instruments implemented it. However, its recognition as an efficient methodology for the control of variability was obtained in General Electric [1].

The application of SS evolved rapidly to other sectors, and, already in the year 2000, its applications were associated with plant distribution [2] and education [3], and it was formally established as a methodology for control of quality [4,5]. According to their use, SS can be defined as a methodology for the continuous improvement of customer satisfaction thanks to a reduction of defects in products/services to increase economic benefits [6].

Although SS can be defined in many ways, from a statistical viewpoint, it is a controlled production process methodology with a near-perfect rate of 3.3 defects per million opportunities. This is perhaps the most important definition of SS as a methodology, since it implies that processes must be appropriately standardized [7]. However, as a procedure, SS is also treated as

an integrated methodology consisting of two sub-methodologies: defining, measuring, analyzing, improving, and controlling (DMAIC), used when products or processes are in existence; and defining, measuring, analyzing, designing and verifying (DMADV), used when products or processes are not in existence and the company needs to develop them [8]. In this research, SS is considered as a methodology integrating other techniques, but this research is only focused on DMAIC, due to the geographical context.

Products/services defects are areas of opportunity that can be addressed with SS. Examples of companies having successfully implemented this methodology in the 1990s include Motorola, General Electrics, and Allied Signals [9]. Investments in education and training in these companies showed remarkable cost–benefit relationships. Unfortunately, since not every organization implementing SS obtains satisfying results, it is important to identify the critical success factors (CSF) of this methodology to prevent companies from throwing SS projects away.

It is common for managers to think that SS is not a suitable methodology to be implemented because its benefits are obtained only in specific contexts. Fortunately, current studies have demonstrated that SS is not only appropriate for manufacturing systems, but also for the services sector [10].

Research has provided an overview of the critical success factors of SS for countries such as India [11], Brazil [12,13], Malaysia [14], Italy [15], and Mexico [7]. Some factors seem to be consistent across countries, whereas others greatly differ, especially in industrial contexts. For instance, authors such as Chakraborty and Chuan Tan [16] reported the 19 critical success factors of SS for the services industry in Singapore, while Jayaraman et al. [17] found 25 of these factors for Malaysian industries. As regards Australian industries, a study conducted by Kumar et al. [18] discussed 14 critical success factors for SS implementation. Finally, a study led by Lande et al. [19] managed to compare the key success factors from different countries thanks to a collection of 63 SS-related scientific articles. Thus, there are many reports from industries that have successfully implemented SS, and for a full report, please consult Kwak and Anbari [20].

Organizational learning, a culture of innovation and change, leadership, consistency, *Communication*, integration, understanding of the SS principles, and managerial commitment are some of the most reported critical success factors of SS [19]. However, being SS a methodology, we believe that the first implementation stages have an impact on subsequent ones. Therefore, it is important to analyze, from a quantitative perspective, how and to what extent SS implementation stages are interrelated.

The literature also reports education and training as key factors to explain the success of SS. In this sense, some companies measure the cost–benefit relationship of investments in education and training as an efficiency indicator [21]. In any case, an educated and trained workforce, which is also expert in the necessary tools for SS deployment, helps companies improve *Communication* and solve problems more efficiently. Consequently, the learning process and feedback are facilitated thanks to shared experiences [22]. Obviously, companies invest in a complete education and training process to obtain the best *Operational benefits*, which would reflect on product quality and process cycle times. However, we should bear in mind that, to obtain such benefits and a strong competitive advantage, teamwork is also crucial [23].

Although many studies have identified the critical success factors of SS across contexts and industrial sectors, few of them have managed to find how these factors are interrelated and to what extent, especially in Mexican maquiladora sector. Moreover, there seems to be no consensus regarding the level of importance of these critical success factors in the SS implementation process in the manufacturing industry. To address these gaps, our research quantifies the impact of education and training (access to information, *Didactic material*, and understanding of statistical tools) on *Communication* and operational performance using a structural equation model with ten hypotheses. The model is tested statistically with information from Mexican maquiladora and focused on DMAIC

only, because there is a product or process in existence and the problem to solve is the quality in production lines.

The main motivation for this research is that, in Ciudad Juárez (Mexico), there are 326 maquiladora companies, which are subsidiaries that belong to foreign companies established in other countries, but that perform activities of assembly of products in other countries. Those maquiladoras are characterized by having an extensive import of raw materials, and export of finished products, since the production and assembly process is carried out in Mexico, and SS is considered an efficient methodology to ensure quality. Nevertheless, there is an special emphasis on the role of access to information, training in *Statistical techniques* and teaching material, as well as the administration and *Communication* of knowledge to achieve *Operational benefits*.

The remainder of this paper is structured as follows: Section 2 proposes and justifies the research hypotheses; Section 3 describes the methods used to test such hypotheses; Section 4 presents our findings; and Section 5 discusses the research conclusions and industrial implications of results.

2. Background and Hypotheses Formulation

The objective of this study is to quantify the relationships among education, training, *Communication*, and *Operational benefits* under a SS implementation scenario. In this section, we describe these four variables and explain how they can be measured.

2.1. Education in Six Sigma

Education is a pillar of SS implementation. In this research, education has been divided into three latent variables: access to *Information*, use of *Statistical techniques* and use of *Didactic material*.

2.1.1. Access to Information

It is important to exploit all the resources to gather information for the SS project at a planning stage before its execution. In this sense, it is common to consult data on similar SS initiatives previously taken on with success [24]. Black Belts (BBs) and Green Belts (GBs) should assist the information retrieval process, since they know best the company's achievements. However, if it is difficult to find what information is needed for a specific project; project leaders and members must make use of all the information and communication technologies put at their disposal [25].

Access to *Information* is essential when implementing a SS project. If gathered data are not reliable, this might compromise the project's ability to solve the problem that it aims at tackling [26]. However, we should bear in mind that BBs and GBs have the responsibility to control the kind of information that can be accessed and how it may be disclosed [27].

To measure *Information* as a latent variable, the following items, previously studied in other research works, were taken into account:

- Easy access to information [6,14]
- Relevant information found in the company's databases [15,19,28]
- Protection of information obtained from SS projects [15,29]
- Access to other company departments when information is not available in one of them [6,15]
- Rules for information protection and confidentiality [15,30]

2.1.2. Statistical Techniques for Six Sigma

Once the company has defined the problem to be solved, project leaders must find in which *Statistical techniques* project members must be trained [31]. For the basic techniques, it is important to be familiar with key concepts such as measures of central tendency and measures of dispersion [32]. By internalizing these notions, operators can more easily understand what is meant by simple regression, multiple regression, experiments design, and variance analysis, among a few concepts.

To analyze this variable, we took into account the following items:

- Use of root cause analysis tools [14]
- Use of the DMAIC technique [14,19]
- Problem identification through statistical tools [6,30]
- Use of specialized software [19,21]
- Use of graphs and statistics [30]

The use of one or another statistical technique always depends on the type of problem to be solved. For this reason, we propose our first working hypothesis as follows:

Hypothesis 1 (H₁). *Analyzing Information for SS projects has a positive direct impact on the types of Statistical techniques to be taught.*

2.1.3. Didactic Material

Education and training programs are designed according to the very specific needs of each project. This means that *Didactic material* (DMs) greatly vary across organizations [33], yet all of them must aim at helping workers better understand the SS methodology. Likewise, all education and training resources must address both theoretical and practical aspects to allow employees to present some of the company's success stories. Moreover, DMs should not be used for a single project; instead, information contained in a given material should be available for future projects [31]. This education and training process plays a key role in company performance [34].

To measure this latent variable, we considered the following items:

- DMs contribute to a better understanding of how SS works and is used [6]
- BBs appropriately explain the objective of the DM [14,21]
- DMs help execute an SS project [6,19]
- DMs are useful in other SS projects [30,35]
- DMs and BBs instructions are understandable [6,36]

Since the focus of DMs varies depending on the type of problem to be solved and the kind and amount of information that is available, we propose the second working hypothesis as follows:

Hypothesis 2 (H₂). *Information available for SS projects has a positive direct impact on the types of Didactic material to be used during the education and training process.*

The content of DMs must deal with the *Statistical techniques* to be taught. Similarly, facilitators (BBs and GBs) have to master all the contents. For these reasons, we propose our third research hypothesis below:

Hypothesis 3 (H₃). *The Statistical techniques of SS to be taught have a positive direct impact on the Didactic material.*

2.2. Communication

Communication—both horizontal and vertical—is another critical success factor of SS. Because this methodology does not work in isolation, an appropriate flow of *Information* inside the organization is of vital importance [37]. As a means to reach or improve *Communication*, BBs and GBs can organize meetings with their group members on a regular basis to discuss the progress of projects that they have taken on and provide/receive feedback. Such reunions would allow SS teams to make the necessary changes to the projects and to appropriately allocate resources to reach the goals planned [38].

To measure the level of *Communication* that companies have during the SS implementation process, we took into account the following variables:

- BBs, GBs, and project leaders organize meetings [28,29]
- The BB and GB provide support in measuring variables and obtaining information [15,28]
- Group members inform of their progress to their peers [28,35]
- Group members talk about their problems with an SS project [6,19]
- Work teams share their experience among them [21,30]

The *Communication* flow within an organization depends on many factors. Perhaps one of the most important is the extent to which employees receive assistance when analyzing and interpreting information and when identifying measurement and control variables [39]. Considering this fact, we propose our fourth research hypothesis as follows:

Hypothesis 4 (H$_4$). *The amount of Information available during SS implementation has a positive direct impact on Communication inside work teams.*

The types of *Statistical techniques* used for SS implementation are another factor contributing to an appropriate *Communication* flow. Techniques that are easy to understand will be quickly communicated horizontally among group members; however, more complex procedures for statistical analysis may require greater vertical *Communication* between team members and BBs or GBs [40]. Similarly, *Communication* can be compromised when team members are novice users of some specialized software. In such cases BBs and GBs, which know best how to use such software, have to assist their fellow team members during the information analysis process. This would ensure that figures and mathematical models contain accurate information and present it appropriately [41].

Considering the impact of *Statistical techniques* on the *Communication* flow in organizations implementing SS, we propose our fifth working hypothesis as follows:

Hypothesis 5 (H$_5$). *Statistical techniques used in SS implementation have a positive direct effect on the quality of Communication.*

Didactic material is a third factor contributing to effective *Communication*. Questions may arise among team members regarding how such materials must be interpreted and analyzed; therefore, it is important to plan regular meetings to provide training and feedback as well as allow team members to share their experiences using such materials [42]. Similarly, to avoid misunderstandings, managers must make sure that all team members are familiar with basic SS concepts [43]. Finally, research has demonstrated that clear *Didactic material* increases self-confidence when initiating new projects and contributes to effective *Communication* [44].

Thus, considering the impact of training and education resources on *Communication*, we propose the sixth working hypothesis below:

Hypothesis 6 (H$_6$). The *Didactic material* used during the SS implementation process has a positive direct impact on *Communication*.

2.3. Operational Benefits of Six Sigma

One of the main contributions of this research is that we relate the critical success factors of SS to their corresponding benefits. *Operational benefits* are perhaps the most commonly reported of all benefits of SS, although there is also a great amount of literature regarding *Economic Benefits* [20]. Among the main *Operational benefits* of SS, we can find:

- Quality or service perceived by customers [45]
- Cycle time reduction [46]
- Increased employee performance [23,45]
- World-class standards [20,47]
- Waste reduction [23,47]
- Increased teamwork [45,48]
- Multifunctional employees [46,47]

These *Operational benefits* are one of the main reasons for SS implementation. However, companies must know which the most efficient ways to obtain them are. Which activities guarantee them? Which critical success factors favor them? A great number of factors may allow companies to boost their operational performance, yet *Information* is perhaps the most crucial of these factors. If *Information* is not reliable, a project may be poorly designed or the possible alternatives to a problem can be incorrectly analyzed [49]. Likewise, problems may be incorrectly defined if information is not accurate, thereby leading to a loss of money and time.

Considering the impact of having reliable and enough *Information* on *Operational benefits*, our seventh working hypothesis reads as follows:

Hypothesis 7 (H7). *Information used during SS implementation has a positive direct impact on Operational benefits.*

Statistical techniques are another source of operational performance at all SS implementation stages: problem definition, project execution, and project control [21]. In addition, besides supporting the problem identification process, *Statistical techniques* support other tools, such as the DMAIC approach [50]. This approach is an equivalent of the scientific method applied to the industrial context. The DMAIC approach is commonly adopted by industries worldwide, since its implementation, combined with SS, has reported remarkable success stories.

Therefore, since we believe that *Statistical techniques* have a positive impact on *Operational benefits* under a SS implementation scenario, we propose our eighth research hypothesis as follows:

Hypothesis 8 (H8). *Statistical techniques used during SS implementation have a positive direct effect on Operational benefits.*

The *Operational benefits* of SS also depend on the quality of the *Didactic material* employed to teach and train workers in the SS methodology. As previously mentioned, if this material lacks clarity, team members may analyze and/or interpret results incorrectly [51]. The responsibility of BBs and GBs is therefore to ensure that every team member is provided with clear and correct instructions during the training sessions [34,43]. This would contribute to minimizing waste, which is one of the objectives of SS from a statistical point of view [37]. This discussion regarding the role of *Didactic material* in *Operational benefits* under a SS implementation scenario allows us to propose our ninth research hypothesis below:

Hypothesis 9 (H9). *The Didactic material used to teach and train in SS has a positive direct impact on Operational benefits.*

Communication is another critical success factor of SS with a strong impact on *Operational benefits*. If BBs and GBs do not organize meetings with their fellow team members, they may be missing important opportunities to supervise projects, provide feedback, and take timely decisions [52]. Similarly, training and education sessions are key moments to communicate the different notions of quality, and they would indirectly minimize conflicts and crises in the company, since products and services will be standardized as a result of *Communication* [53]. Finally, *Communication* is the means to

reach collaboration [38]. Companies that do not communicate their success may cause their employees to work on their own, which contradicts the objective of SS [54]. Following this discussion, we propose our tenth and last working hypothesis as follows:

Hypothesis 10 (H$_{10}$). *Communication in a SS implementation scenario has a positive direct impact on Operational benefits.*

Figure 1 depicts the ten research hypotheses proposed and previously discussed into a structural equation model, integrated according to dependence established among latent variables.
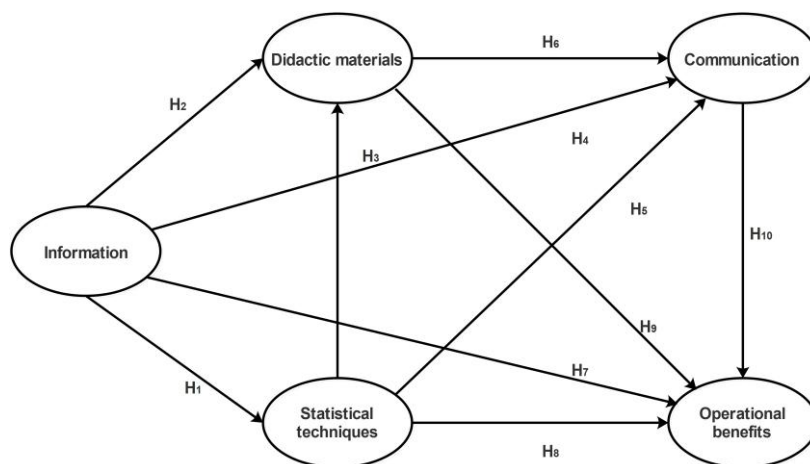

Figure 1. Proposal model.

3. Methodology

To reach our objective and validate the ten hypotheses depicted in Figure 1, we adopted the following methodology.

3.1. Defining Variables and Creating the Survey

In this research, we discuss three basic concepts related to SS: *Education and Training* (*Information*, *Didactic material*, and *Statistical techniques*), *Communication*, and *Operational benefits.* To find the observed variables of each of these concepts, we conducted a literature review on databases such as Sciencedirect, Ingenta, and Ebscohost, among others.

Once we identified the observed variables, we constructed a survey. The literature review thus represented the rational validation of this survey [55,56], which was composed of three sections. The first section was aimed at collecting sociodemographic data of the participants, and the second section assessed the critical success factors of SS. As regards the third section, it analyzed the different types of SS benefits; however, for the purpose of this study, only took into account items collecting data on *Operational benefits* were taken into account.

The first version of the survey was submitted to a content validation among a group of subject-matter experts. The purpose of the experts validation was to make sure that our instrument had been appropriately adapted to the context of the research [57,58], since data had been collected from previous studies conducted worldwide, not just in Mexico.

Finally, the survey had to be answered using a five-point Likert scale, where a one value indicated that an SS activity was not important or an SS benefit was never obtained. On the other hand, the highest value indicated that an SS activity was highly important or an SS benefit was always obtained. Values of two are used for activities frequently executed or benefits gained, while three for regular, and four for usually.

3.2. Survey Administration

The model and its hypotheses were validated with data collected from the Mexican maquiladora industry during May to July 2016. More specifically, we administered the survey to manufacturing company managers, GBs, BBs, Champions, and group leaders having at least two years of experience in SS or who had participated in SS initiatives at least three times. A list of maquiladoras, manager names and contact information was provided by AMAC (Maquiladoras Association AC) and then, survey administration meetings were scheduled in advance to managers having experience in SS implementation, and the questionnaire was to be answered individually. After a first interview with managers, the snowball method was used to identify other possible responders (managers, green belts, black belts and champions).

However, for participants who cancelled the meeting three times, we stopped insisting due to time restrictions.

3.3. Data Capture and Validation

We constructed an electronic database with gathered data using SPSS software. Then, we performed a screening process to identify missing values and outliers, which were replaced by the median value of items. However, cases or surveys showing more than 10% of missing values were removed.

Latent variables were validated through the following indices:

- Cronbach's alpha and composite reliability index: Used to measure internal validity. Acceptable values must be higher than 0.7 [57,59].
- R-Squared (R^2) and Adjusted R-Squared: Used to measure the predictive validity of dependent latent variables from a parametric perspective. Acceptable values must be higher than 0.2 [60].
- Q-Squared (Q^2): Used to measure predictive validity from a non-parametric perspective. Acceptable values of Q^2 must be similar to their corresponding R^2 and adjusted R^2 values [60].
- Average Variance Extracted (AVE): Used to assess convergent validity, setting 0.5 as the threshold [61].
- Variance Inflation Factors (VIFs): Used as a measure of collinearity. Acceptable values must be below 3.3 [62].

Note that sometimes it is possible to increase the Cronbach's alpha value in a latent variable after removing items that seem to compromise its validity. For this reason, we ran several iterations to validate each latent variable.

3.4. Descriptive Analysis of the Sample

At this stage, we created contingency tables to analyze trends in the sample characteristics. As previously mentioned, we analyzed the genre of participants, number of SS projects that they had taken on, company size, and industrial subsector, among a few.

3.5. Descriptive Analysis of Items

Since we worked with ordinal data, we used the median as a measure of central tendency and the interquartile range (IQR) as a measure of data dispersion. Both measures helped us identify which SS activities and benefits are the most important to manufacturing companies, from the sample's viewpoint. High median values indicated that an SS activity was important to the sample or an SS benefit was always obtained, whereas low median values indicated that an SS activity was not important to the sample or an SS benefit was not obtained. As regards the IQR, high values revealed low consensus among respondents regarding the median value of an item. Low IQR values revealed high consensus among respondents with respect to the median value of an item.

3.6. Hypotheses Validation

To validate the research hypotheses, we created a structural equation model (SEM) using WarpPLS v.5. This software relies on partial least squares (PLS) and is regularly recommended for studies working with Likert scales, small samples, and non-normal data [39]. Likewise, WarpPLS v.5 has been a useful tool for validating theories in SS research. For instance, it was reportedly employed to know the impact of knowledge created in SS on organizational performance [45].

Before interpreting the model, we analyzed its efficiency by computing the model fit and quality indices in Table 1 [63]:

Table 1. Indexes for model validation.

Index	Acceptable If	Description
Average Path Coefficient (APC)	*p*-value < 0.05	Hypotheses significance
Average R-Squared (ARS)	*p*-value < 0.05	Predictive model validity
Average Adjusted R-Squared (AARS)	*p*-value < 0.05	Predictive model validity
Average block Variance Inflation Factor (AVIF)	<3.3	Collinearity among latent variables
Average Full collinearity VIF (AFVIF)	<3.3	Collinearity among latent variables
Tenenhaus Goodness of Fit (GoF)	>0.36	Data fit to model
Simpson's Paradox Ratio (SPR)	>0.7	Direction in relationship
R-Squared Contribution Ratio (RSCR)	>0.7	Direction in relationship
Statistical Suppression Ratio (SSR)	>0.7	Direction in relationship
Nonlinear Bivariate Causality Direction Ratio (NLBCDR)	>0.7	Direction in relationship

Once the model proved to be statistically stable, we proceeded to interpret it. For this interpretation, we analyzed three types of effects in every relationship:

Direct effects: They validate hypotheses presented in Figure 1. Every direct effect corresponds to a hypothesized relationship between latent variables.
Indirect effects: These occur between two latent variables through a mediating variable.
Indirect effects are always interpreted using two or more model paths.
Total effects: They are the sum of direct and indirect effects in a relationship.

All effects were associated with a beta (β) value—expressed in standard deviations—and a *p*-value for the statistical significance of effects at a 95% confidence level, thus setting 0.05 as the cutoff and testing the null hypothesis: $\beta = 0$, against the alternative hypothesis: $\beta \neq 0$. Finally, every effect also included an effect size (ES) to represent the amount of R^2 or explained variance contained in dependent latent variables [64].

4. Results and Discussion

After three months of administering the survey, from May to July 2016, we collected 323 surveys or cases, but only 301 of them were analyzed, since the remaining ones presented more than 10% missing values and were excluded. Results from the data analysis are discussed in the following subsections.

4.1. Descriptive Analysis of the Sample

Table 2 presents the sample's characteristics regarding surveyed industries and job positions. As it can be observed, 289 participants reported information on these two aspects, and the automotive industry was the most surveyed. Similarly, men represented the majority of the sample, whereas only 83 women participated in the study. As regards job positions, 88 Champions, 69 Master Black Belts (MBs), 64 Black Belts (BBs), and 80 Green Belts (GBs) formed the sample.

Table 2. Industrial sector and years of experience.

Industrial Sector	Years or Experience on SS					Total
	2–3	2–4	4–5	5–10	>10	
Automotive	49	48	41	27	16	181
Electric	13	4	6	5	5	33
Machining	8	7	10	3	2	30
Electronic	9	3	7	1	2	22
Medical	1	6	4	2	3	16
Aeronautic	2	0	2	1	2	7
Total	82	68	70	39	30	289

4.2. Descriptive Analysis of Items

Table 3 presents the descriptive analysis of the latent variables and their corresponding items, also known as observed variables. Data are organized in descending order, according to the median value of items. In this sense, it should be noted that none of the items from the critical success factors of SS showed a median value above four, although they are all higher than three. On the other hand, two *Operational benefits* had a median value greater than four, meaning that they are usually obtained in Mexican manufacturing industries.

Table 3. Measures of central tendency and dispersion.

Latent Variable	Observed Variables (Items)	Percentile			IR
		25	50	75	
Information	Rules for information protection and confidentiality	2.893	3.811	4.658	1.766
	Protection of information obtained from SS projects	2.737	3.659	4.521	1.784
	Access to other company departments when information is not available in one of them.	2.684	3.659	4.545	1.861
	Relevant information found in the company's data bases	2.538	3.506	4.426	1.889
	Easy access to information	2.353	3.311	4.270	1.917
Statistical techniques	Use of graphs and statistics	3.022	3.956	4.750	1.728
	Use of root cause analysis tools	2.838	3.776	4.624	1.786
	Problem identification through statistical tools	2.774	3.693	4.556	1.782
	Use of specialized software	2.602	3.654	4.570	1.968
	Use of the DMAIC technique	2.670	3.651	4.543	1.874
Didactic material	DMs and BBs instructions are understandable	2.937	3.717	4.528	1.591
	DMs contribute to a better understanding of how SS works and is used	2.676	3.667	4.526	1.850
	DMs help execute an SS project	2.718	3.659	4.540	1.821
	DMs are useful in other SS projects	2.754	3.642	4.497	1.743
	BBs appropriately explain the objective of the DM	2.669	3.629	4.512	1.843
Communication	The BB and GB provide support in measuring variables and obtaining information	2.626	3.639	4.533	1.907
	Work teams share their experience among them	2.629	3.635	4.540	1.911
	Group members talk about their problems with an SS project	2.662	3.592	4.459	1.797
	BBs, GBs, and project leaders organize meetings and reunions	2.564	3.572	4.481	1.917
	Group members inform of their progress to their peers	2.544	3.552	4.487	1.943
Operational benefits	Quality or service perceived by customers	3.139	4.112	4.846	1.708
	Cycle time reduction	3.140	4.010	4.763	1.622
	Waste reduction	3.085	3.988	4.734	1.648
	World-class standards	3.069	3.964	4.742	1.673
	Increased employee performance	3.044	3.918	4.721	1.677
	Increased teamwork	3.009	3.888	4.704	1.695
	Multifunctional employees	2.797	3.836	4.716	1.918

In addition, from this descriptive analysis it is important to highlight the following results:

- *Information* should be highly accessible, yet in this research it holds the last position. On the other hand, it seems that such *Information* is highly protected, since this item holds the first place.
- Graphs and statistics seem to be common tools when deploying SS projects in Mexican manufacturing companies, since this item was ranked first within latent variable *Statistical techniques*. However, the use of the DMAIC approach seems to be far less important, since it was ranked last. Unfortunately, when companies do not promote the use of this approach, operators may feel afraid of joining work and improvement teams.
- As regards *Didactic materials*, the item referring to clear instructions from instructors showed the highest median. This implies that leaders responsible for training and education programs are competent professionals.
- Support and assistance from BBs and GBs is the most important item from latent variable *Communication.* On the other hand, progress monitoring and supervising held the last place in this analysis. Unfortunately, if SS projects are not regularly monitored and supervised, it may be difficult to detect deviations on time.
- As regards *Operational benefits,* results indicate that Mexican manufacturing companies remarkably improved their product quality as a result of SS implementation. Such results reflect the objective of SS, which is to minimize defects in products and services. However, the analysis also indicates that a multidisciplinary workforce is a much less common benefit of SS.

4.3. Validation of Latent Variables

Table 4 introduces results obtained from the data validation process. Based on such results, the following conclusions were reached:

- All latent variables had enough predictive validity from both parametric and non-parametric perspectives, since all R^2, Adjusted R^2, and Q^2 values were higher than 0.2. Moreover, all Q^2 values were similar to their corresponding R^2 values.
- All latent variables had enough internal validity, since the Cronbach's alpha and the composite reliability index were higher than 0.7 in all cases.
- All latent variables reported enough convergent validity, since all AVE values were higher than 0.5.
- All latent variables were free from collinearity problems, since the VIFs values were lower than 3.3.

Table 4. Validation for latent variables.

Index	Latent Variable				
	Didactic Material	*Statistical Techniques*	*Communication*	*Operational Benefits*	*Information*
R-squared	*0.652*	*0.553*	*0.636*	*0.603*	
Adjusted R-squared	0.65	0.552	0.632	0.597	
Composite reliability	0.913	0.915	0.947	0.925	0.905
Cronbach´s alpha	0.872	0.883	0.93	0.906	0.869
Average variance extracted	0.723	0.683	0.781	0.639	0.657
Full collinearity variance inflation factor	3.261	3.109	2.973	2.491	2.868
Q-squared	0.653	0.552	0.635	0.606	

4.4. SEM Evaluation

The model depicted in Figure 1 was tested using the model fit and quality indices described in the methodology. The list below shows the obtained values for these indices. In addition, the tested version of the model is presented in Figure 2:

- Average path coefficient (APC) = 0.333, $p < 0.001$
- Average R-squared (ARS) = 0.611, $p < 0.001$
- Average adjusted R-squared (AARS) = 0.608, $p < 0.001$
- Average block VIF (AVIF) = 2.810, ideally ≤ 3.3
- Average full collinearity VIF (AFVIF) = 2.940, ideally ≤ 3.3
- Tenenhaus GoF (GoF) = 0.652, large ≥ 0.36
- Sympson's paradox ratio (SPR) = 1.000, ideally = 1
- R-squared contribution ratio (RSCR) = 1.000, ideally = 1
- Statistical suppression ratio (SSR) = 1.000, acceptable if ≥ 0.7
- Nonlinear bivariate causality direction ratio (NLBCDR) = 1.000, acceptable if ≥ 0.7
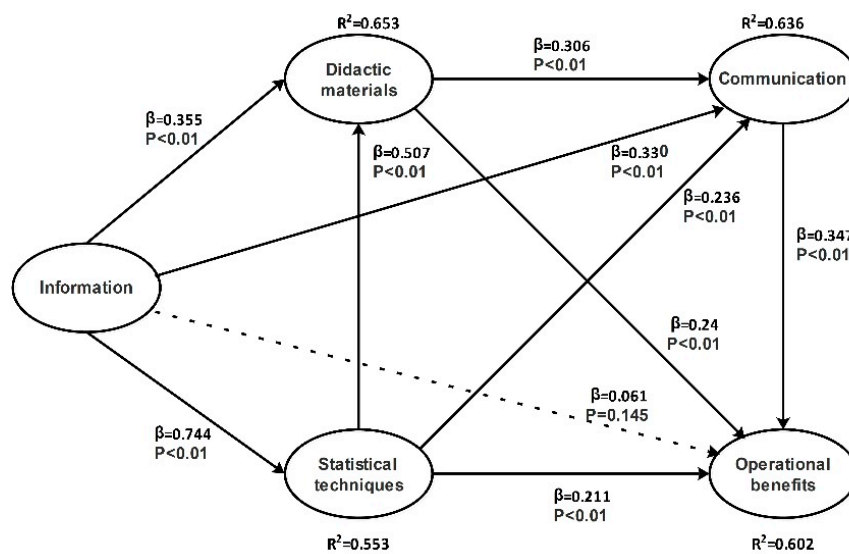
Figure 2. Evaluated model.

These results suggested the existence of no collinearity problems in the proposed model; thus, we could successfully analyze and interpret its values. In this sense, in Figure 2, we associated every relationship with a beta (β) value and a *p*-value. The former represents a dependency measure whereas the latter is the significance value for the hypothesis testing. In addition, each dependent latent variable included an R^2 to indicate its amount of explained variance. After analyzing such values, we found nine statistically significant relationships, depicted as solid lines, and one statistically not significant relationship, illustrated as a dotted line.

4.4.1. Direct Effects: Hypotheses Evaluation

Table 5 presents the results from the hypotheses evaluation. For a hypothesis to be statistically significant at a 95% confidence level, its corresponding *p*-value had to be lower than 0.05. For every hypothesis, the table specifies which dependent (DLV) and independent (ILV) latent variables were involved, the beta and its *p*-value, and its acceptance into or rejection from the model.

Table 5. Conclusions about hypotheses.

Hypothesis	ILV	DLV	β	*p*-Value	Conclusion
H_1	*Information*	*Statistical techniques*	0.744	<0.01	Accepted
H_2	*Information*	*Didactic material*	0.355	<0.01	Accepted
H_3	*Statistical techniques*	*Didactic material*	0.507	<0.01	Accepted
H_4	*Information*	*Communication*	0.330	<0.01	Accepted
H_5	*Statistical techniques*	*Communication*	0.236	<0.01	Accepted
H_6	*Didactic material*	*Communication*	0.306	<0.01	Accepted
H_7	*Information*	*Operational benefits*	0.061	0.145	Rejected
H_8	*Statistical techniques*	*Operational benefits*	0.211	<0.01	Accepted
H_9	*Didactic material*	*Operational benefits*	0.240	<0.01	Accepted
H_{10}	*Communication*	*Operational benefits*	0.347	<0.01	Accepted

4.4.2. Effect Sizes

Effect sizes indicate the contribution of an independent latent variable to the R-Squared coefficient of its corresponding dependent latent variable. Table 6 shows the effects size for every relationship. It should be noted that latent variable *Statistical techniques* was 55.3%, explained by a single independent latent variable: *Information,* whereas in the remaining relationships, the dependent latent variables were explained by two or more independent latent variables. For instance, we found that *Didactic material* was 65.3%, explained by *Statistical techniques* and *Information,* the former being responsible for 39.2% of the variability, and the latter explaining 26.1%. The remaining relationships were similarly interpreted.

In addition, considering the ES values, we reached the following conclusions:

- Latent variable *Statistical techniques* is the most important when explaining the variability of *Didactic material*, being ES = 0.392.
- Latent variable *Information* is key to explaining the variability of *Communication* (ES = 0.242), although *Didactic material* seems to have a similar effect on it (ES = 0.224).
- Latent variable *Communication* is a crucial element for obtaining *Operational benefits*, since ES = 0.249.

Table 6. R-squared contribution to dependent latent variable.

To	From				R^2
	Didactic Material	*Statistical Techniques*	*Communication*	*Information*	
Didactic material		0.392		0.261	0.653
Statistical techniques				0.553	0.553
Communication	0.224	0.17		0.242	0.636
Operational benefits	0.168	0.146	0.249	0.039	0.602

4.4.3. Sum of Indirect Effects

Indirect effects between two latent variables occur through a mediating variable. Table 7 presents the sum of indirect effects between latent variables, the *p*-value for the statistical hypothesis testing, and the effect size.

After analyzing the research hypotheses (see Section 4.4.1), we found that latent variable *Information* did not have a statistically significant effect on *Operational benefits*; however, its indirect effect is statistically significant, and it explained up to 35.1% of the variability of *Operational benefits*. This is the largest indirect effect reported in the model, with β = 0.585. From a similar perspective, we found that *Information* had a statistically significant indirect effect on *Communication* thanks to latent variables *Statistical techniques* and *Didactic material.* In this case, although the direct effect also reported a statistically significant value (β = 0.330), the indirect effect was much larger (β = 0.399).

In conclusion, latent variable *Information* had statistically significant indirect effects on all the remaining latent variables, and such effects were the largest ones. For this reason, it was placed in the top left-hand corner of the model.

Table 7. Sum of indirect effects.

To	From		
	Didactic Material	*Statistical Techniques*	*Information*
Didactic material			0.377 ($p < 0.001$), ES = 0.277
Communication		0.155 ($p < 0.001$), ES = 0.112	0.399 ($p < 0.001$), ES = 0.293
Operational benefits	0.106 ($p = 004$), ES = 0.074	0.257 ($p < 0.001$), ES = 0.178	0.585 ($p < 0.001$), ES = 0.351

4.4.4. Sum of Total Effects

The total effects of a relationship are the sum of its direct and indirect effects. As Table 8 demonstrates, the ten total effects that we found were statistically significant at a 95% confidence level, since all *p*-values were below 0.05. In addition, the analysis revealed that latent variable *Information* affected all the other latent variables and also caused the largest total effects. In this sense, its total effects on *Statistical techniques* are worth being highlighted. *Information* directly influenced *Statistical techniques* in 0.744, but it was also indirectly responsible for its variability in 53.8% because the effect size is 0.538. Such high value in that relationship indicates that *Information* is a pillar of SS, but also it is required a good *Statistical technique* for analysis.

Table 8. Sum of total effects.

To	From			
	Didactic Material	*Statistical Techniques*	*Communication*	*Information*
Didactic material		0.507 ($p < 0.001$) ES = 0.392		0.732 ($p < 0.001$) ES = 0.538
Statistical techniques				0.744 ($p < 0.001$) ES = 0.553
Communication	0.306 ($p < 0.001$) ES = 0.224	0.391 ($p < 0.001$) ES = 0.282		0.729 ($p < 0.001$) ES = 0.535
Operational benefits	0.346 ($p < 0.001$) ES = 0.243	0.468 ($p < 0.001$) ES = 0.324	0.347 ($p < 0.001$) ES = 0.249	0.646 ($p < 0.001$) ES = 0.421

Currently, it is not enough to have access to information to guarantee the SS success, a deep analysis is required and modern techniques must be used, such as big data. In addition, the relationship between *Information* and *Communication* is very high with a beta value of 0.729, indicating that the knowledge must be transmitted and saved an important resource.

5. Conclusions and Industrial Implications

In this study, we assessed 20 activities related to educational processes (*Information*, *Statistical techniques*, and *Didactic material)* and *Communication* as critical success factors of SS. We associated these activities with seven *Operational benefits* of SS. In the multivariate analysis performed on 301 surveys, all SS activities showed a median value higher than 3 but lower than 4, implying that they are regularly performed in the Mexican manufacturing sector. On the other hand, two of the seven *Operational benefits* reported a median value higher than 4, thereby implying that they are always obtained.

Although Mexican manufacturing companies seem to rely on effective rules to guarantee confidentiality of *Information*, SS team members report that access to such data as resource material to plan and start SS projects is not easily granted. Organizations should further analyze this issue, since it may affect employee engagement in SS initiatives. In other words, it is good to motivate employees to improve the production process, but it is equally important to grant them access to the necessary data and information, especially during the first implementation stages of an SS project. If companies do not work on this, SS projects are likely to be incorrectly planned, because of a lack of information related to the production process status. However, this can be a hard activity, because

that production process can generate much information for different departments and data analysis requires big data techniques.

As regards *Statistical techniques*, graphs and figures seem to be the main statistical tool to support SS, whereas the DMAIC approach proved to have a less significant place among Mexican manufacturing companies. Such results suggest that organizations approach SS as a statistical technique rather than as a problem-solving methodology. It is important for companies to find a balance between these two conceptions [20], otherwise SS may become a significant obstacle for those who are not experts in statistics [65]. In this sense, other studies, having detected an imbalance between the different ways SS can be approached, also report that, in such cases, SS projects are more often abandoned [66,67] and that is why this is an opportunity for techniques such as big data or novel techniques to help analyze information obtained from production process, because it allows finding trends, as it is applied in education [68], and SS is a philosophy based in education and training.

In addition, our study reports that GBs and BBs usually provide clear instructions on how to work with *Didactic material*. However, we also found that this material is not always useful for future projects, and team members must thus be trained every time they initiate a new project with SS, which increases final costs. Concerning *Communication*, GBs and BBs in Mexican manufacturing companies seem to provide appropriate and sufficient assistance to team members; nevertheless, when it comes to supervising and monitoring SS projects, their performance appears to be less regular. Sadly, employees may lose their motivation when they perceive a lack of consistency when it comes to monitoring projects [69].

Finally, product quality and process cycle time reduction seem to be the main *Operational benefits* of SS, whereas teamwork and multifunctional skills are less common. In this case, it is important to add human attributes to SS, since human resources know the administrative procedures, the production processes, and the company's opportunities for improvement [21,70].

After analyzing the relationships between the latent variables, the following conclusions regarding direct effects were reached:

- *Information* available to solve problems defines which *Statistical techniques* employees will be trained and how *Didactic material* must be designed, so they can be clear to all team members and reusable in future projects. However, big data can be implemented as a *Statistical technique* for yellow belts, green belts and champions, because it can help to find hidden patterns into *Information*.

- Having available *Information* does not automatically guarantee *Economic Benefits*, because direct effect is statistically not significant. First, managers must be focused on teaching and training employees in the use of the necessary *Statistical techniques* through clear and meaningful *Didactic material*. The fact that *Information* does not have a direct impact on *Economic benefits* implies that it is not appropriately analyzed or it cannot directly become a benefit. *Communication* and education are therefore required, and managers should be part of appropriate *Communication* channels and training sessions. However, managers must also encourage that workers integrate in SS projects and share the knowledge gained among them as a way to disseminate their experiences solving problems.

- *Information* has a direct effect on *Statistical techniques*, which denotes the importance of this variable at the first implementation stages of an SS project, where employees identify the problem and define it. In addition, *Information* has the largest direct effects on all subsequent latent variables, meaning that, if *Information* is not reliable or easily accessible, companies must have problems implementing SS and probably, they abandon this philosophy, resulting in a lack of quality in their production process.

- Another important relationship involves *Statistical techniques* and *Didactic material*. This relationship again reflects the importance of education and training for an appropriate SS implementation. In fact, the three largest effects, considering the β values, involve the three latent variables that make up the education process.

- Managers and SS members must strive to implement an appropriate education and training scheme in which *Information* is reliable but also easily accessible. Likewise, education and training must focus on the use of basic *Statistical techniques* through clear *Didactic material*, since these three variables affect *Communication*, both vertical and horizontal. In other words, without a suitable education and training process, *Information* cannot properly flow; consequently, all involved variables may diminish the indirect effects that *Information* has on *Economic benefits* through *Communication* as the mediating variable.

6. Limitations and Future Research

The set of hypotheses that have been proposed in the model that associates access and quality of information with *Didactic material* and *Statistical techniques*, as well as with *Communication* processes and *Operational benefits*, have been tested with information from Mexican maquiladora industry, thus, in another sector and country, it is possible to obtain different results.

In future work, we will get information from industries in other regions of the country to perform comparative analyses to identify the factors that are best associated with SS implementation process. Similarly, given that maquiladoras are a globalized phenomenon, comparisons can be made between countries in South America.

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