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PROGRAMA
Doctorado en Ciencias y Tecnologías Industriales

Modelos causales para la implementación de herramientas de manufactura esbelta y cadena de suministro

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Tesis Doctoral

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SECCIÓN I: SOBRE LA TESIS Y AUTORIZACIÓN

Sobre esta tesis

La memoria de esta tesis se presenta en la modalidad de compendio de artículos publicados en revistas científicas internacionales con revisión por pares e indexadas en el Journal Citations Reports (JCR). Los trabajos publicados se indican a continuación:

Publicación 1: García-Alcaraz, J.L., Avelar-Sosa, L., Latorre-Biel, J.I., Jiménez-Macías, E., Alor-Hernández, G. Role of Human Knowledge and Communication on Operational Benefits Gained from Six Sigma. Sustainability 2017, 9(10), 1721. September 2017. https://doi.org/10.3390/su9101721. Factor de impacto (2017): 2.075 (Q2 en Tecnología de Ciencias Verdes y Sustentables)

Publicación 2: García-Alcaraz, J.L., Alor-Hernández, G., Sánchez-Ramírez, C., Jiménez-Macías, E., Blanco-Fernández, J. and Latorre-Biel, J.I. Mediating Role of the Six Sigma Implementation Strategy and Investment in Human Resources in Economic Success and Sustainability. Sustainability 2018, 10(6), 1828. June 2018. https://doi.org/10.3390/su10061828. Factor de impacto (2017): 2.075 (Q2 en Tecnología de Ciencias Verdes y Sustentables)

Publicación 3: García-Alcaraz, J.L., Maldonado-Macías, A.A., Alor-Hernández, G., Jiménez-Macías, E., Sáenz Díez Muro, J.C., and Blanco-Fernández, J. Impact of human factor on flexibility and supply chain agility of La Rioja wineries. European J. Industrial Engineering, Vol. 11, No. 5, 2017. https://doi.org/10.1504/EJIE.2017.087703. Factor de impacto (2017): 1.085 (en Investigación de Operaciones y Ciencias Administrativas).

AUTORIZACIÓN DE LOS DIRECTORES DE TESIS A PRESENTAR LA TESIS DOCTORAL *"MODELOS CAUSALES PARA LA IMPLEMENTACIÓN DE HERRAMIENTAS DE MANUFACTURA ESBELTA Y CADENA DE SUMINISTRO"* EN MODALIDAD DE "COMPENDIO DE PUBLICACIONES:

VºBº Directores de Tesis

Fdo.: Juan Ignacio Latorre Biel   Fdo.: Emilio Jiménez Macías

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Dedicatoria

El ser humano se inspira siempre en algo cuando se ha fijado un objetivo. En este caso, mi inspiración se encuentra en mi familia, por lo que quiero dedicar este trabajo a las siguientes personas:

- A mi hijo *Jorge Andrés García-Rodríguez* por enseñarme a ser un padre y permitirme ver en sus ojos la inocencia que se ha convertido en mi razón de vivir.
- A mi hija *Mariana Odette García-Rodríguez*, quien a sus 11 años pasó sus vacaciones trabajando conmigo en los artículos publicados para alcanzar este grado. Es una lástima que no aparezca como autora. Gracias hija por enseñarme que el amor es infinito.
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- A mis hermanos y hermanas (sanguíneos o no), ya que los verdaderos aprendizajes y valores los obtuve con ellos en casa o en logia.
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Tabla de Contenido

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SECCIÓN II: INTRODUCCIÓN GENERAL

Presentación de los artículos

En esta sección se presenta una breve introducción a la tesis, así como a los artículos que han sido resultado de la misma, dado que su presentación es por compendio de publicaciones.

Introducción general

Esta tesis que se titula *Modelos causales para la implementación de herramientas de manufactura esbelta y cadena de suministro,* tal como su nombre lo indica, tiene dos temas centrales que son una preocupación constante para los gerentes en las empresas, la cual se refiere a la calidad de los productos y la cadena de suministro de éstos, así como de sus materias primas.

Los temas no son nada nuevos, ya que en la actualidad existen muchos artículos que abordan ambos temas (calidad y cadena de suministro), aunque si se observan áreas de oportunidad aún. Por ello, con relación a la calidad, en esta tesis se presentan dos artículos publicados en revista indexada, cuyo tema central es seis sigma (SS) como filosofía aplicada a los sistemas de producción con la finalidad de garantizar productos homogéneos y que cumplan los estándares demandados por los clientes. En relación con este tema, es importante mencionar que SS no es una filosofía que ha reportado amplios beneficios a las empresas y sus orígenes se remontan a décadas pasadas, sin embargo, no ha perdido su aplicabilidad y eficiencia en la industria y no ha dejado de ser un tema de interés de académicos y gerentes industriales.

En la Figura 2.1 se ilustra la tendencia que han tenidos las publicaciones que tienen en su título la frase "seis sigma", misma que se ha buscado en la base de datos de Sciencedirect, donde claramente se observa una tendencia creciente en los últimos quince años. Mas específicamente, esa tendencia es más clara a partir del año 2010, donde la globalización industrial y productiva se encontraba en pleno auge y la calidad se veía como una de las ventajas competitivas que puede alcanzar la empresa a través de SS. En promedio, en base a la ecuación de tendencia lineal que se realiza al conjunto de puntos, se puede decir que cada año se incrementa el número de artículos en aproximadamente 167.62 unidades en relación a seis sigma.

Analizando las cifras del año 2018, aun cuando el análisis es realizado en el mes de septiembre, se observa que, faltando tres meses para la culminación del mismo, ya se ha igualado el número de publicaciones que se tenían en el año 2017. Esas tendencias muestran la importancia que tiene todavía SS en los sistemas de producción industrial y seguramente, esa tendencia se mantendrá en años posteriores. Entonces la pregunta que vale la pena hacer, es ¿qué se debe hacer para garantizar el éxito de esta filosofía de producción?

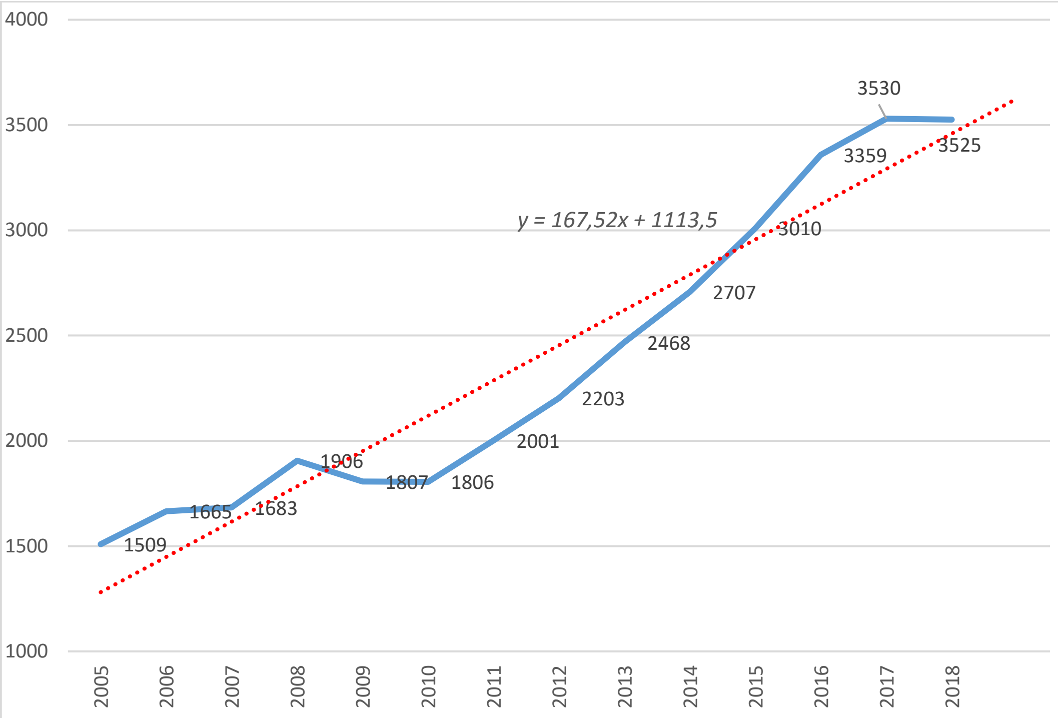

Figura 2.1. Tendencias de publicaciones de seis sigma
Fuente: Sciencedirect (acceso el 27 de septiembre de 2018)

Otra área de oportunidad para obtener una ventaja competitiva por parte de las empresas es la que se relaciona con la administración de su cadena de suministro, ya que algunas veces el costo de transporte y logística de los materiales de un producto representa hasta el 70% del costo de producción (Guo, Tian, Jiang, & Wang, 2018), lo que representa una área de oportunidad en la que se pueden obtener mejoras económicas y es por ello que la CS ha llamado la atención de académicos e industriales en la práctica.

En la Figura 2.2 se ilustran los años y numero de artículos que tienen en el título la palabra "supply chain", donde se puede ver la evolución creciente del concepto desde el año 2005. Se puede observar que en el año 2010 este concepto tiene un resurgimiento con una pendiente positiva, hasta terminar en el año 2018 con 8074 artículos, y faltan tres meses para que el año culmine. Sin duda, que la cantidad de 2017 será ampliamente rebasada.

En base a la línea de tendencia se puede observar que cada año la cantidad de artículos publicados en este tema se incrementa en 533.61 unidades, lo que demuestra el interés que se tienen en esta área de investigación por parte de los académicos e industriales.

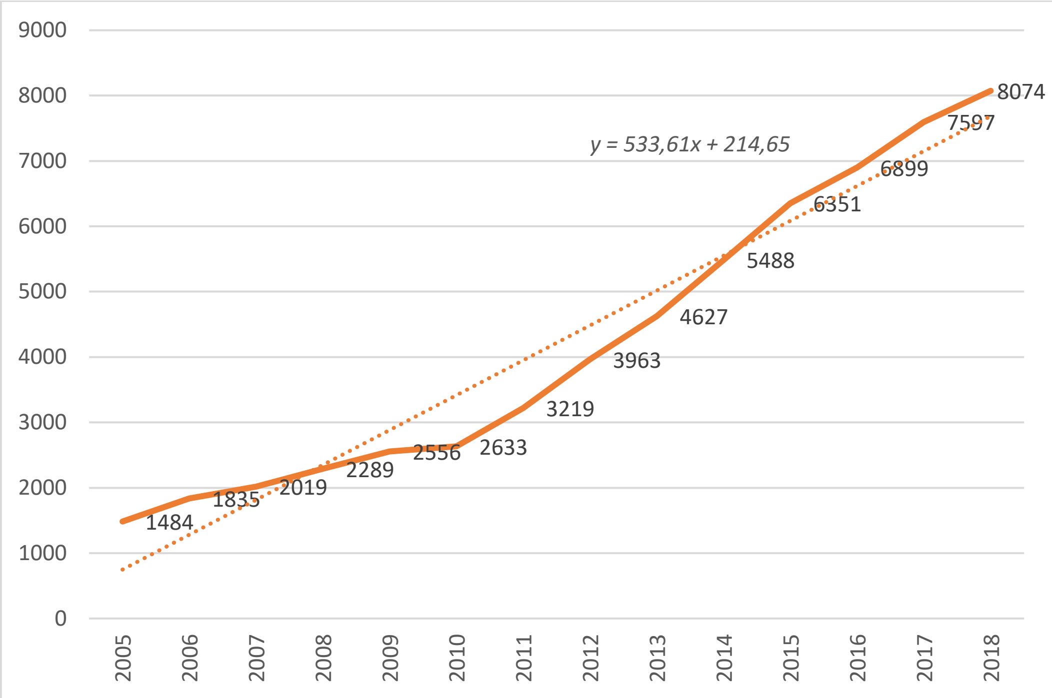

Figura 2.2. Tendencias de publicaciones de seis sigma
Fuente: Sciencedirect (acceso el 27 de septiembre de 2018)

Los enfoques con que se han abordado esas dos temáticas de investigación han sido variados. Por ejemplo, algunos autores buscan identificar los factores críticos que garantizan el éxito de seis sigma y de las cadenas de suministros. Sin embargo, se ha encontrado que muchas de esas variables no son fácilmente cuantificables y que deben ser valoradas por medio de otras, a las que se llama variables observadas, a las que se llamará ítems. Así, una nueva tendencia es que se busque relacionar esos factores críticos de éxito con los beneficios o índices de desempeño de las empresas, por lo que se requiere de modelos causales que permitan cuantificar los efectos de las variables en el desempeño.

En esta tesis se presentan tres artículos en los que se relacionan ciertos factores de éxito de seis sigma y de la cadena de suministro con los índices de desempeño que tienen la empresa, lo que permite cuantificar el impacto y de esta manera identificar aquellas actividades que son esenciales de aquellas que son triviales. Los artículos se describen brevemente a continuación.

Publicación 1: Role of Human Knowledge and Communication on Operational Benefits Gained from Six Sigma

El tema central de este artículo es seis sigma como filosofía aplicada a los sistemas de producción de las industrias maquiladoras establecidas en México. Se presenta un modelo de ecuaciones estructurales para relacionar cuatro variables latentes o grupo de actividades que deben ejecutarse para obtener beneficios operativos al implementarla.

En este artículo se asume que, como filosofía, seis sigma se debe a los recursos humanos que son responsables de implementarla. Sin embargo, para tomar decisiones, se requiere disponibilidad de información relacionada con el área o proceso de producción a mejorar, crear cursos de capacitación en la que se proporcionen los materiales adecuados y se enseñen las técnicas de análisis de información requeridos. Sin embargo, para garantizar el éxito de seis sigma, se requiere de comunicación de esa información en todos los niveles, por lo que este modelo integra las siguientes variables latentes:

1. Información (5 ítems)
2. Material didáctico (5 ítems)
3. Técnicas estadísticas (5 ítems)
4. Comunicación (5 ítems)
5. Beneficios operacionales (7 ítems)

La suma total de variables observadas es de veintisiete, de las cuales veinte se deben a factores críticos de seis sigma y siete a beneficios operativos como consecuencia de la correcta implementación.

En este modelo se asume que la disponibilidad a la información y su acceso son la clave del éxito, por lo que es la variable latente independiente que se coloca en la parte izquierda del modelo. De la misma manera, los beneficios operativos son la respuesta o consecuencia de la ejecución de las actividades que comprenden los ítems, por lo que es la variable dependiente y se coloca en la parte derecha del modelo.

Se han planteado diez hipótesis que relacionan a las variables latentes y se justifica cada una de ella. Para la validación de éstas se usa la técnica de mínimos cuadrados parciales integrada en el software WarpPLS 6 ®, lo que permite obtener una medida de dependencia que indica en unidades de desviación estándar los efectos directos entre cada una de las variables. De la misma manera se estimaron los efectos directos e indirectos entre las variables latentes.

La contribución principal de este artículo es que cuantifica las relaciones entre las variables latentes asociadas a los recursos humanos y sus actos, de manera que los gerentes observen de manera tangible la importancia que tienen éstos, así como el acceso a la información y su calidad, así como la capacitación que se les brinde en técnicas estadísticas y la importancia de usar el material didáctico adecuado para poder implementar seis sigma en los procesos de producción y obtener los beneficios operativos que se ven reflejados en los índices de desempeño.

El modelo se evalúa con información de 289 encuestas obtenidas de la industria maquiladora de exportación de México. De los resultados obtenidos de este artículo, se puede concluir lo siguiente:

- La información generada de los procesos productivos de una empresa por sí sola no genera ningún beneficio al implementar seis sigma, sino que debe ser analizada por operarios que estén altamente capacitados con material didáctico adecuado en técnicas estadísticas; pero, además, debe ser fiable.
- La existencia de información promueve la comunicación entre los responsables de la implementación de seis sigma, pero los gerentes deben buscar la forma de presentarla de manera sencilla y entendible para los usuarios.
- El uso de material didáctico en los cursos de formación y capacitación para seis sigma depende de las técnicas estadísticas que deben aprenderse, así como de la naturaleza de la información existente.
- La comunicación es una variable que tiene efectos directos de los materiales didácticos que se usan en el proceso de capacitación, así como en la información y las técnicas estadísticas, pero la primera variable es la más importante debido al tamaño del efecto directo y por tal motivo, los gerentes deben enfocarse en que esa información sea accesible y organizada de tal manera que sea fácil de entender por todas las personas integradas en los grupos de mejora.
- Los beneficios operacionales obtenidos de seis sigma tienen efectos directos de las información, las técnicas estadísticas usadas en el análisis, materiales didácticos y comunicación, pero es ésta última variable la que tiene un mayor efecto. Lo anterior indica que los gerentes deben enfocarse en gestionar la comunicación entre los integrantes de los grupos de mejora.
- La educación y entrenamiento son la base del éxito de seis sigma, la cual se debe fundamentar en la existencia de información clara y accesible. Lo anterior demuestra que los recursos humanos son la base de seis sigma como filosofía de producción y por ello la alta gerencia y responsables de la toma de decisiones deben enfocarse en la educación y entrenamiento.

Publicación 2: Mediating Role of the Six Sigma Implementation Strategy and Investment in Human Resources in Economic Success and Sustainability

Al igual que la publicación 1, este artículo tiene como tema central la filosofía seis sigma en los procesos productivos, aunque contiene un modelo más sencillo en relación a las variables que integra y la cantidad de hipótesis que se usan para relacionarlas.

En la publicación 1 se demostró que los recursos humanos eran un factor importante en la implementación de seis sigma, por lo que es necesario que se encuentren debidamente capacitados para poder realizar las mejoras que les demanden los sistemas productivos, sin embargo, para ello se requiere de inversión y esa decisión corresponde a la alta gerencia. Asimismo, en el éxito de esta filosofía es importante la forma en que se realiza la implementación de seis sigma y ellos depende de los directivos de la empresa, por lo que en este artículo se analizan cuatro variables latentes como una continuación de la primera publicación, donde la respuesta ya no son los beneficios operativos, sino los beneficios económicos que son el objetivo final de la empresa. Así, las variables latentes que se analizan son las siguientes:

- Compromiso gerencial (5 ítems)
- Estrategia de implementación (5 ítems)
- Inversión en recursos humanos
    - Educación y entrenamientos (5 ítems)
    - Incentivos (5 ítems)
- Beneficios económicos (5 ítems)

Es importante mencionar que en esta ocasión la variable relacionada con la inversión en recursos humanos se ha dividido en dos variables a su vez, ya que se considera que debe existir inversión en su educación y entrenamiento de manera indirecta, pero también deben existir programas de incentivos y reconocimientos para los participantes en proyectos de seis sigma.

Las cuatro variables se relacionan mediante cinco hipótesis que relacionan a las variables latentes, mismas que han sido validadas estadísticamente mediante la técnica de modelado de ecuaciones estructurales y se ha ejecutado el modelo en el software WarpPLS 6 ®. El resultado que se obtiene es una medida de la dependencia que existen entre las variables como efecto directo, la cual es expresada en desviaciones estándar. Asimismo, se estiman los efectos indirectos y totales entre las variables.

Este artículo tiene como contribución principal el obtener una medida del efecto que tiene el compromiso gerencial con los programas de seis sigma y los requerimientos de éste, tales como la inversión en los recursos humanos asociados a la educación y recompensas con su trabajo, para finalmente ver el impacto en los beneficios económicos.

El modelo planteado se evalúa estadísticamente con información proveniente de 301 encuestas realizadas a la industria maquiladora de México, misma que está representada principalmente por el sector automotriz y eléctrico/electrónico. De los resultados del modelo evaluado se obtienen las siguientes conclusiones:

- La calidad de un producto industrial proviene no solamente de los materiales usados como insumos, sino del nivel de conocimiento que tengan los empleados para generarlo de acuerdo a las especificaciones del cliente. Por ello, los gerentes deben invertir en los recursos humanos para capacitarlos en las diferentes técnicas de solución de problemas, tales como seis sigma, pero, además, deben establecer programas de reconocimiento para aquellos empleados que obtengan los resultados planeados en su proyectos de mejoramiento continuo y seis sigma.
- Los gerentes siempre deben planear la forma en que desean implementar seis sigma en sus empresas, ya que de ellos depende la estrategia que se debe seguir y de ésta a su vez, los planes y programas de educación e incentivos que se tendrá con los empleados. Seis sigma requiere inversión económica, para lo cual debe haber planes y programas, lo que se conoce como estrategia de implementación y solamente los responsables de la alta gerencia pueden autorizar los fondos económicos para ello.
- Aunque se ha mencionado que la inversión en recursos humanos es importante en la obtención de los beneficios económicos de seis sigma, en esta investigación se ha encontrado que la estrategia de implementación establecida por la alta gerencia es más importante, ya que tiene un mayor efecto directo, lo cual no quiere decir que los operarios no sean importantes.
- Aunque la inversión en recursos humanos depende de la estrategia de implementación y del compromiso gerencial, se observa que de manera directa esta última variable es más importante, lo cual tiene sentido, ya que la misma estrategia depende del compromiso gerencial.
- Como conclusión general se puede mencionar que el éxito de seis sigma depende en su mayoría del compromiso gerencial, de la forma de aplicarla en la industria y de los niveles de inversión que se realice en los operarios, ya que son éstos quienes la aplican en realidad en el sistema productivo en base a las ordenes e intrusiones que reciben.

Publicación 3: Impact of human factor on flexibility and supply chain agility of La Rioja wineries

El tema central de este capítulo es la cadena de suministro, específicamente los relacionados a la flexibilidad y agilidad que se alcanza con una adecuada capacitación de los recursos humanos, ya que se asume que éstos son la base de los logros que se puede obtener en las formas de generar servicios y la rapidez con que se hace. Las variables latentes que integra este modelo son solamente tres y son las siguientes:

- Factor humano (3 ítems)
- Flexibilidad del proceso de producción (6 ítems)
- Agilidad de la cadena de suministro (5 ítems)

La suma de variables observadas que se integran en este análisis es de 14 y se asume que el rol del factor humano es como variable independiente, el rol de la flexibilidad del proceso de producción es como variable mediadora y finalmente, la agilidad de la cadena de suministro es la variable de respuesta o independiente y aparece al lado derecho del modelo.

Se proponen solamente tres hipótesis entre las variables analizadas y se justifica desde un punto de vista técnico la relación entre éstas. Con esas variables y sus hipótesis se presenta un modelo de ecuaciones estructurales simple, mismo que es evaluado en el software WarpPLS 6 ®, donde se analizan los efectos directos, indirectos y totales. Es importante mencionar que para cada una de las variables latentes dependientes se reporta el valor de R-cuadrada como una medida de la varianza explicada que tienen en ella las variables independientes.

La principal contribución de este artículo que cuantifica la relación que existe entre las variables asociadas a factores humanos, flexibilidad del proceso de producción y la agilidad de las cadenas de suministro, pero aún más importante es el contexto en el cual se realiza la investigación, ya que se aplica a la industria del vino de la Comunidad Autónoma de La Rioja, ya que los casos reportados en los que se analizan esas variables en la cadena de suministro se refieren a la industria manufacturera.

El modelo se evalúa con solamente 64 empresas vitivinícolas, lo que representa un porcentaje elevado de los establecimientos que se encuentra en La Rioja. Se usan varios índices para evaluar la validez de las variables latentes y del modelo en sí. De los resultados obtenidos, se puede concluir lo siguiente:

- Al igual que en muchos procesos productivos, en este estudio se ha demostrado que los recursos humanos son la base que permite a las empresas vitivinícolas generar flexibilidad y agilidad de su cadena de suministro.

- La flexibilidad del proceso de producción es esencial para alcanzar la agilidad de la cadena de suministro, ya que deben tenerse siempre vías alternas para realizar las ordenes de producción exigidas por los clientes.

La flexibilidad del proceso productivo es la variable que más afecta a la agilidad de la cadena de suministro.

SECCIÓN III. ARTÍCULOS PUBLICADOS

sustainability

MDPI

Article

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

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

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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

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

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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

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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.

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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 (H_1). *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 (H_2). *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 (H_3). *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:

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- 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 (H_7). *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 (H_8). *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 (H_9). *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.

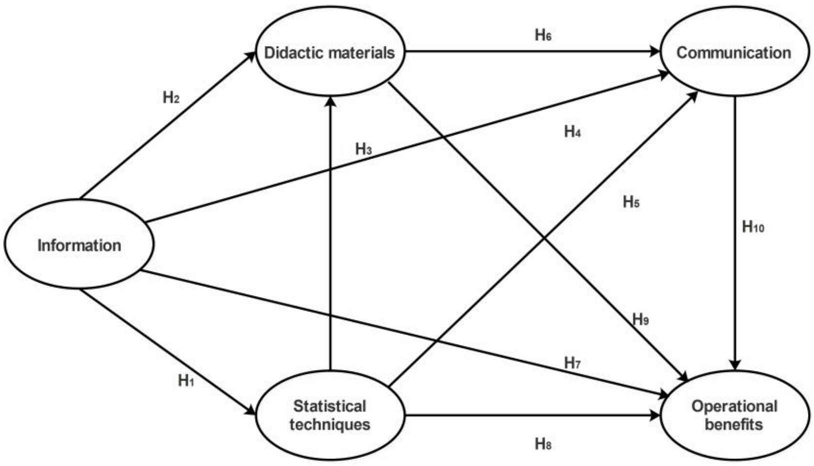

Figure 1. Proposal model.

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.

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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

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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:

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- 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 $\leq$3.3
- Average full collinearity VIF (AFVIF) = 2.940, ideally $\leq$3.3
- Tenenhaus GoF (GoF) = 0.652, large $\geq$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 $\geq$0.7
- Nonlinear bivariate causality direction ratio (NLBCDR) = 1.000, acceptable if $\geq$0.7

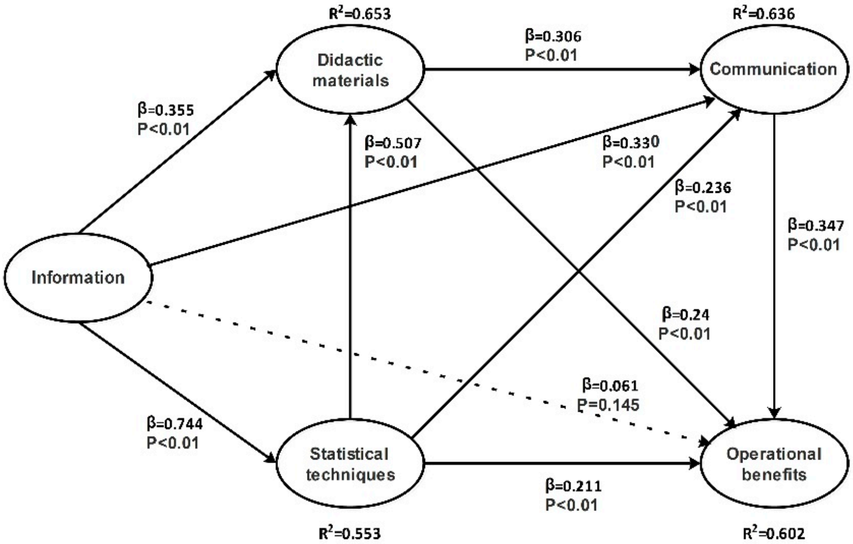

Figure 2. Evaluated model.

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.

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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

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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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Mediating Role of the Six Sigma Implementation Strategy and Investment in Human Resources in Economic Success and Sustainability

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Abstract: Six Sigma is a methodology widely used in manufacturing production to guarantee quality and several factors facilitate its success. This paper presents a structural equations model to identify the relationships between managerial commitment, Six Sigma implementation strategy, investments in human resources and the economic benefits obtained; and five hypotheses are proposed. These variables are also related to sustainability, especially human resources, a paradigm very combinable with Six Sigma. The model is evaluated using partial least squares and information obtained from 301 Mexican manufacturing companies from different industrial sectors. The results indicate that managerial commitment is the basis for Six Sigma success, but requires an adequate implementation strategy focused on customers and their needs, which must integrate an investment plan in human resources that is focused on training and teamwork. In addition, managers must have a reward program that encourages motivation and recognizes the achievements of the human resources involved.

Keywords: six sigma; total quality management; quality assurance; investment in human resources

1. Introduction

Six Sigma (SS) is a methodology focused on the improvement of manufacturing processes, where product quality is the response variable for all preceding activities. The aim of SS is to produce no more than 3.4 defects per million opportunities, making it an appealing proposition for production managers [1,2]. Although its 1980s origins might suggest that SS is an outdated methodology, quality has always been a requirement in companies' products and services, and its usage can still offer effective quality assurance for clients and according to de-Felipe and Benedito [3], SS is still a methodology worldwide used for support quality and recent studies in industrial and services sector prove it; as for example, Inal Tamer et al. [4] report how SS improve clinical laboratory efficiency, Randell et al. [5] report how SS improve the autoverification process in clinical chemistry

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and immunoassay, Smętkowska and Mrugalska [6] report a case study for improving the quality in a production process.

Likewise, it is observed that SS is a production philosophy that has remained at the forefront because it can be linked to aspects of vital importance to the company, such as sustainability, currently there are reports that indicate it; for example, Cherrafi et al. [7] propose a framework for integrating green production processes with SS, Zhu et al. [8] in their research are linking SS to environmental sustainability in a hospital, Radziwill [9] proposed SS as a tool that supports sustainability and finally, Cherrafi et al. [10] conduct a literature review that links lean manufacturing, SS and sustainability, and argue the need to generate models that support those relationships.

There are now many companies established in Europe and America reporting *Economical benefits* following the implementation of SS. While benefits had already been seen by Japanese companies, the American companies were the first to disseminate their results, resulting in a rapid uptake of SS by other companies [10]. It is widely considered that Motorola was the first company to report the successful implementation of SS, and this was followed by other industries, such as IBM, AlliedSignal, General Electric, Ford, General Motors and Chrysler. A list of other companies reporting successful implementation of SS can be found in Kwak and Anbari [11].

Nevertheless, some companies have not experienced the same success when implementing SS, resulting in a wasted expense of both time and money [12]. Four causes of SS failure are reported, including lack of understanding of the concept and scope of the methodology, inadequate education and training, poor management and implementation strategies, and lack of supporting organisational structure [13,14].

Given the above, one question needs to be addressed: what are companies that have managed to adequately implement SS doing and what are companies who have failed not doing? Some responses are given by Montgomery Douglas [12]; however, he suggests that there is a set of key activities involved in the implementation of SS, known as critical success factors (CSFs), which have been widely reported in the literature. In 2002, Coronado and Antony [15] published research in which they carried out a literature review in relation to the critical success factors that have been identified since Motorola's introduction of SS in 1986. Four years later, in 2006, Revere et al. [16] updated this list, based on an empirical analysis, and in 2009, Vest and Gamm [17] also carried out a literature review and a comparison of SS and the Lean Toyota Production System.

The studies referred to above, which were applied in different environments, suggest that SS as a philosophy greatly depends on the human resources and the environment in which it is implemented. Even Chow Ann and Moseley James [18] report in their study the relationship between human resources and the success of SS. Reported critical success factors that are local and applied in specific industrial sectors may not be applicable to all companies, and implementation without adjusting to the environment may be another factor involved in failure. Brun [19] conducted a study to determine whether Italian companies implement the concepts of SS in the same manner as Motorola or in their own way, while Desai et al. [20] carried out a similar study on Indian companies, where it was found that the SS application differed on the basis of the size of the company. Habidin and Yusof [21] created a structural equation model to identify the main CSFs for SS in the automotive industry in Malaysia, which was also the location for similar studies by Chakraborty and Chuan Tan [22], who identified 42. Ribeiro de Jesus et al. [23] investigated companies in Brazil, while Cano et al. [24] investigated CSFs using a literature review. More reports on critical success factors for SS can be found in other literature [1,23,25–27]. An analysis of the various CSFs for SS in different countries can be found in Lande et al. [28].

The number of CSFs identified for SS varies considerably between studies. Kumar et al. [29], for example, identify 14, where the predominant activities are associated with senior *Managerial commitment*, training and organisational structure, and suggest that the absence of these factors is the main cause of abandonment of SS projects. Marzagão and Carvalho [27] identify 12 CSFs, adding aspects associated with the use of statistical tools and information technology to the above list, as well as the need for projects to be small in scale to ensure completion in the correct timeframe and form, given that if the expected results are not rapidly achieved, there is a risk of loss of motivation among the improvement teams. Fairul-Anwar and Mohd Amran [30] published a study with five CSFs for SS, reduced from a list of 97, where SS *Implementation strategy*, training and education in SS, and *Managerial commitment* again predominate.

American companies that have implemented SS generally report *Economical benefits* resulting from the application and implementation of these CSFs. There are, however, many other benefits to be gained. Kwak and Anbari [11] carried out a literature review, identifying 14 companies that have benefitted from the implementation of SS. Although these benefits are mainly financial, operational aspects were observed, related to inspection time and quality maintenance, punctual deliveries to clients and reduced cycle time from product design to manufacture. Likewise, Antony et al. [31] report the benefits that SS can provide in the services sector (since this methodology is not exclusive to the manufacturing sector) and, more recently, Raman et al. [32] report eight cases of companies that have benefitted from the implementation of SS, among which *Economical benefits* predominate.

As can be seen from the above, there has been great interest in identifying the critical success factors for SS and its benefits, but few studies associate these CSFs with the benefits obtained. García-Alcaraz et al. [33], for example, performed an analysis to relate human factors with operational benefits, such as productivity, product rejection levels and client complaints. At the same time, Marzagão and Carvalho [27] propose a structural equation model in which SS is a variable affecting companies' economic performance. Nevertheless, there has been no in-depth analysis of aspects associated with SS implementation, nor their relationship with *Investment in human resources*.

Based on the assumption that SS is a philosophy, that it is associated with human resources and that it depends on management decisions, the supporting organisational structure and the *Implementation strategy* followed in order to ensure the attainment of the *Economical benefits* reported in the literature [18,34], the aim of this article is to relate the critical success factors for SS to the *Economical benefits* obtained and that is its main contribution; and not only to the *Economical benefits*, but indirectly to sustainability, as this paradigm is strongly affected by *Economical benefits*, and especially by SS and human resources (HR). To this end, second-order structural equation modelling is used to relate *Managerial commitment* to SS, SS *Implementation strategy* and *Investment in human resources*, which in turn comprises two latent variables associated with education and training for SS and incentives awarded to improvement teams for achieving their goals. All these variables are related to the *Economical benefits* that can be obtained from SS.

Following this introduction, the second section of this article justifies the relationships between the latent variables in the model, which are hypotheses to be demonstrated statistically. The third section defines the methodology followed to validate the relationships between the variables in the model, while section four reports the findings, section five presents the discussion and industrial implications associated with these findings and finally, section six presents future research opportunities.

2. Literature Review and Hypotheses

The structural equation model presented here includes four latent variables: *Managerial commitment*, *Implementation strategy*, *Investment in human resources* (education/training and incentives) and *Economical benefits*. These variables are described below, with justification for the relationships between them.

2.1. Managerial Commitment (MC)

Given that SS is considered a production philosophy, the management and their activities are the main human resources factor that should be considered when analysing the SS *Implementation strategy*. There are many studies that associate *Managerial commitment* with successful SS implementation, including Vest and Gamm [17], who state that management is responsible for establishing a work plan for SS implementation and for directing the practices and techniques for improving processes, and Fairul-Anwar and Mohd Amran [30], who use affinity diagrams to integrate CSFs into just five groups, where *Managerial commitment* tops the list.

Recent studies by Alhuraish, Robledo and Kobi [25] propose a list of 13 critical success factors, where *Managerial commitment* is the first, but other important factors can be identified, including communication, training for everyone involved, abilities and skills acquired, as well as knowledge transfer at all administrative levels, all of which must be encouraged by senior management. Similarly, Mustafa and Jamaluddin [1] determine that *Managerial commitment* is the basis for successful SS, since managers are responsible for both steering the company through their actions and properly managing the knowledge that is generated during projects.

Laureani and Antony [35] indicate that the main role of managers is to lead and monitor SS projects, provide the resources for their implementation and establish work policies for the improvement teams. At the same time, management must also carry out a process for integrating the different departments of which the company is comprised, which enables everyone to have common objectives in their SS projects.

To determine *Managerial commitment* to the SS implementation process, for the purposes of this research, it is necessary to assess whether managers perform the following activities [36–39]:

- Management regularly reviews the progress of six sigma projects (MC1);
- Management encourages knowledge transfer across different departments and the organisational structure (MC2);
- Management encourages interdepartmental cooperation in planning six sigma projects (MC3);
- Management requests reports on the progress of projects in each department (MC4);
- Management assigns the appropriate personnel for each project (MC5).

2.2. Six Sigma Implementation Strategy (IS)

As has been stated above, *Implementation strategy* is one of the main determinants in SS abandonment and failure, and is therefore considered a critical success factor. As far back as 1998, Harry [40] suggested that this strategy is vital for success and that it is the responsibility of senior management to establish guidelines, disseminate them throughout the company and ensure that everyone understands them. Drohomeretski et al. [41], meanwhile, state that SS is in itself both a methodology and a production strategy. Consequently, its establishment corresponds to senior management and it should be based on the experience of the organizational structure created for this purpose (Green Belts, Black Belts and Yellow Belts). Fatemi and Franchetti [42], however, state that the management leadership should be capable of combining it with other existing techniques and methodologies, such as lean production, and should focus many of these products on solving client problems.

Andersson et al. [43], in a study carried out on telecommunications companies, state that it is necessary for management to encourage frequent meetings between SS project leaders not only with the aim of promoting knowledge transfer between them and sharing experience, but also to analyse the problems encountered when implementing SS and identify ways to resolve them. Finally, Drohomeretski, Gouvea da Costa, Pinheiro de Lima and Garbuio [41] suggest that SS should not be conceived merely as a philosophy, but should be based on the outcomes of operations carried out from an operational and administrative standpoint.

Likewise, Kumar et al. [44] state that the best approach to implementing SS is client-oriented, since it is the client who demands product quality, and SS projects should therefore focus on addressing their complaints and suggestions in order to maintain client loyalty. Niemes [45] suggests that SS is a methodology that will bring a significant increase in sales and that SS projects should therefore focus on solving the technical and operational problems that will lead to better quality, because this will represent greater income, as suggested by Madhani [10].

To ensure that there is an adequate SS *Implementation strategy* in place, the following should be verified [10,41,43,45–47]:

- There is an organisational structure that supports six sigma, including Black Belts, Green Belts and Yellow Belts (IS1);
- Meetings are held between six sigma project leaders and project team members to enable monitoring (IS2);
- Six Sigma projects are related to clients' demands (IS3);
- Improvement teams are aware of clients' requirements (IS4);
- Department heads review clients' demands and complaints before creating a six sigma project (IS5).

Considering that SS strategy and its development depends on the actions taken by management, the following hypothesis is proposed.

Hypothesis 1 (H1). *Managerial commitment to SS projects has a direct and positive effect on the Implementation strategy for this philosophy.*

2.3. Investment in Human Resources for SS (HRI)

Alongside SS *Implementation strategy*, lack of training and knowledge of SS are also reported as determinants in abandonment and failure. Considering that SS is a philosophy, it corresponds that investments should be made in the education of human resources, since it is they who are responsible for implementing the projects [48]. Two types of investment are associated with human resources: those involving educational processes, during which statistical techniques are taught, and systems for rewarding a job well done.

2.3.1. Education and Training (ET)

With regard to investment in education and training for SS, Coronado and Antony [15] state that specialised education is required for those implementing SS projects, since they need to learn aspects related to statistical techniques for analysing information. It is the management's responsibility to establish training schedules, which should be agreed with Champions, Green Belts and other people involved who understand training requirements, and this will enable the determination of course content [1]. At this point it is important to point out that management must accept that it is the responsible body and leader for all SS projects and that productivity indices will be related to the educational and training level of the teams implementing SS projects [49].

To ascertain whether the company is implementing an adequate educational process as part of its *Investment in human resources*, the following should be verified:

- There is a regular training schedule (ET1);
- Blank belts (BBs) and Green belts (GBs) are assigned to advise on six sigma projects (ET2);
- BBs and GBs are involved in the analysis of problems associated with the six sigma project (ET3);
- The workload is adjusted to allow time for education and training (ET4);
- Materials and software are provided for analysing the information (ET5).

2.3.2. Incentives (IN)

If an employee does good work on an SS project and the company gains economic profits as a result, they should be rewarded for their efforts in order to maintain their interest and their motivation to continue working on improving production processes. Arumugam et al. [50] suggest that it is necessary to analyse the impact of incentive and reward schemes on the success of SS, since it depends on workers remaining engaged and integrated in the projects. Likewise, Zu et al. [51] state that while incentives should be performance-based for those involved in projects, they should also be focused

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on achieving greater engagement with and involvement in the quality commitments in place. Finally, a review of CSFs for SS by Brun [19] concludes that senior management should find ways to involve employees, providing a clear view of the objectives and proposing a system of incentives.

To ascertain whether a company has an adequate SS incentive programme, the following should be verified:

- Award ceremonies are held for certification as GBs, BBs, etc. (IN1);
- Regular awards are presented for the best six sigma projects (IN2);
- Project outcomes are considered in career performance and impact on the income of project members (IN3);
- The abandonment of an six sigma project affects promotion to higher positions (IN4);
- The outcomes of an six sigma project affect annual bonuses or salary increases at year end (IN5).

In accordance with the above, it can be seen that programmes for *Investment in human resources* depend on the support and level of *Managerial commitment*, and therefore the following hypothesis is proposed.

Hypothesis 2 (H2). *Managerial commitment to SS projects has a direct and positive effect on Investment in human resources, such as education and incentives.*

Nevertheless, these levels of *Investment in human resources* should be part of an SS implementation plan, where education, training, incentives and rewards are essential components in ensuring its success and integrating the participants, i.e., part of the *Implementation strategy*. Mustafa and Jamaluddin [1], for example, state that SS implementation plans should include reward programmes for workers, since it is they who are the means of improving production processes and who truly apply the methodology, and they who best understand the production processes and have the clearest outlook on potential improvements, as suggested by Chen et al. [52] in a Single-Minute Exchange of Die (SMED) case study. According to de Freitas et al. [53], focusing solely on training in statistical techniques can drive many people to abandon SS projects, since this can be an obstacle to learning for many operators, while incentive programmes can provide motivation, preventing abandonment by project team members and encouraging their efforts. Given the above, it can be concluded that the SS *Implementation strategy* affects *Investment in human resources*, and the following hypothesis is proposed.

Hypothesis 3 (H3). *SS Implementation strategy has a direct and positive effect on Investment in human resources associated with education, incentives and rewards.*

2.4. Six Sigma Economical Benefits

SS is a methodology that requires economic investments, which can be justified by the fact that its implementation results in a number of benefits. The literature includes many reported benefits associated with SS and much of its popularity can be traced to this reason, rather than its adoption as a problem-solving philosophy. According to de Freitas, Costa and Ferraz [53], implementing SS can lead to increased morale among employees, cost reductions, increased product reliability, efficient use of resources, reduced risks and enhanced reputation for the company, with clear and significant *Economical benefits*. In the same way, Parast [54] finds a relationship between SS implementation and performance in innovation projects, where companies achieve better market positioning and financial performance.

In addition, Swink and Jacobs [55] and Shafer and Moeller [56] show that there is a relationship between the investment made in SS projects and the *Economical benefits* obtained by companies, with high cost recovery rates. At the same time, Ertürk et al. [57] state that companies who have implemented SS are characterised by reduced costs, improved productivity, growth and market presence, client retention and loyalty, reduced cycle times and defects in processes, greater culture of change and better client service, where many of these characteristics reflect economic profits. Finally, include a list of 14 companies that have obtained benefits through SS implementation, where the financial aspects are again shown.

To evaluate the benefits to a company through SS implementation, the following should be verified:

- there are savings in production costs (ECB1);
- a competitive advantage is created for the company (ECB2);
- there are increased returns on investment (ECB3);
- there are increased sales (ECB4);
- there is reduced wastage (ECB5).

However, the question that needs to be addressed at this point is: which CSFs help ensure that the company gains these economic profits? In this research, two sources are analysed: *Implementation strategy* and *Investment in human resources*. Fatemi and Franchetti [42] indicate that the integration of lean manufacturing programmes, sustainability and SS guarantees that companies will gain economic resources, but success is dependent on the strategy followed to integrate them as a whole. This has also been proposed by Drohomeretski, Gouvea da Costa, Pinheiro de Lima and Garbuio [41], who add that not all outcomes depend on the *Implementation strategy*, but rather on the level of adherence to it and the speed with which deviations are corrected. In other words, it is not enough to have plans and programmes as part of the *Implementation strategy* in order to obtain *Economical benefits*; rather, it is necessary to execute the plans and base decisions on the results of the productive system's operations. Finally, Kumar, Antony, Antony and Madu [44] indicate that companies should take a client-focused approach to their strategic plans and programmes, since it is they who actually pay for the final product and focus on its characteristics. Considering that there is a relationship between SS *Implementation strategy* and the *Economical benefits* that are gained, the following hypothesis is proposed.

Hypothesis 4 (H4). *SS Implementation strategy has a direct and positive effect on the Economical benefits that are obtained from it.*

Although there are many sources of success for SS, *Investment in human resources* is one of the most important. Revere, Kadipasaoglu and Zalila [16] point out that the selection of a team comprising people with training and skills in information management and understanding of production line problems is essential for success and cost reductions in SS projects. At the same time, Moosa and Sajid [58] state that the success of SS as a methodology is highly dependent on the skills and level of training of members of the improvement teams, since good training in statistical techniques and information analysis will result in easier definition of the problem, as well as monitoring of the results obtained, which translates into better performance indices for the company.

Ertürk, Tuerdi and Wujiabudula [57] indicate that lack of a training programme is directly associated with savings in projects, and therefore recommend that BBs and GBs serve as instructors and guides in their implementation. Likewise, Boon Sin et al. [59], using a structural equation model, show that SS projects should be focused on generating and transferring knowledge in relation to the different problems that are encountered by companies and that are associated with clients, since if problems rearise, their solutions are already known, thus saving money for companies.

At the same time, Louhaichi et al. [60] state that the economic incentives that companies offer their employees for their performance on SS projects help to better integrate them, achieving greater motivation and commitment. Anand et al. [61] even suggest that the level of incentives should be based on the level of involvement of team members in an SS project, since incentives often recognise the work of the team as a whole, without taking into account the contribution of informal leaders who often guide other team members. Based on the above, the following hypothesis is proposed:

Hypothesis 5 (H5). *Investment in human resources during SS implementation has a direct and positive effect on the Economical benefits gained by the company.*

The proposed hypothesis is shown in graphic form in Figure 1.

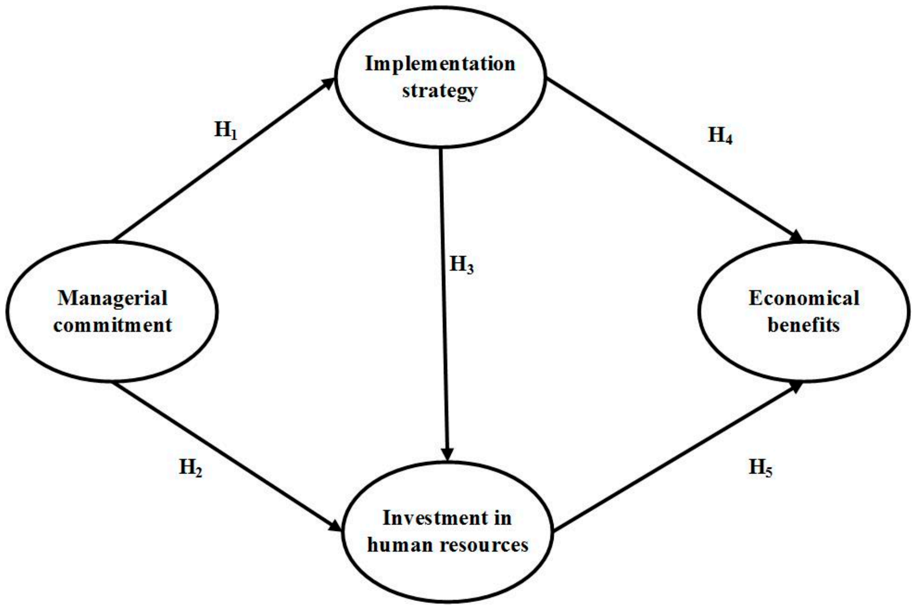

Figure 1. Proposed model.

2.5. Sustainability and Environmental Benefits

Although the model presented in this work apparently is focused only on economic success, the benefits derived from SS *Implementation strategy* and *Investment in human resources* are much more important on other issues related to *Economical benefits* and to SS and HR, especially on sustainability and environment.

Firstly, *Economical benefits* are clearly related to sustainability, since the more resources the company has, the more it is able to devote to sustainable production, and, on the contrary, a small economical capacity drives to the necessity of a production without possibility of environmental processes.

However, the main relationship of or model to sustainability lies in other variables, concretely *Investment in human resources*, as well as in the inherent mutual benefits of the paradigms of SS and sustainability.

Such relationship between both paradigms drives to SS sustainability. McCarty et al. [62] present a guide about SS sustainability devoted to analyze the power of SS to develop and implement enterprise-wide green initiatives, with structures such as program governance, project charters, transfer functions, measurement systems, risk assessment, and process design, based on real-world examples of specific environmental problems. A complete analysis of works integrating lean manufacturing, SS and sustainability can be seen in Cherrafi et al. [63] as, for instance, a particular case study of sustainability framework linked to SS, concretely an automotive company, that can be seen in Tan Owee et al. [64].

SS is also a source of benefits for environmental management systems, as can be seen in Jami et al. [65], with benefits including materials consumption, cost reductions, less waste to the landfill, decreased amount of waste water, reduction of emissions, reduction of energy consumption and safety improvements. Habidin and Yusof [66] present another case study based on an automotive industry.

Finally, the main relationship of sustainability with this model lies in *Investment in human resources*. Ehnert [67] presents a report on the role of HR for advancing sustainability, and Daily and

Huang [68] analyses, based on a quantitative survey, sustainability and HR management, providing a comprehensive review of sustainable HR management combining different disciplines like sustainable work systems, ergonomics, HR management, linking sustainability, among others.

3. Materials and Methods

To quantify the dependency relationships between the four latent variables, the methodology shown below was followed.

3.1. Stage 1: Information Collection

The structural equation model integrates four latent variables associated with SS: *Managerial commitment*, *Implementation strategy*, *Investment in human resources* and *Economical benefits*. For the statistical validation of the model, information was needed from the industry, and therefore a literature review was carried out to identify the observed variables or items that would enable evaluation of these four variables, representing a rational validation. Once the items for the latent variables were identified, a questionnaire was created and submitted to five experts in the area, two academics and three industry managers, constituting expert validation.

The final questionnaire comprises three sections, the first relating to demographic aspects, the second listing all items for each of the latent variables and the third relating to the economic profits gained. The second and third sections of the questionnaire use a five-point Likert-type scale for responses, where a rating of one indicates that the activity is never performed or that the benefit is never obtained, while a rating of five indicates that this activity is always performed, or the benefit is always obtained.

The questionnaire was administered to the Mexican manufacturing industry, using a stratified sample, since it was targeted toward companies who had implemented SS and who had data on projects carried out over the last five years and who also had SS certification such as Green Belt (GB), Black Belt (BB), Yellow Belt (YB) or Champion, which were principles for inclusion. Following this, a snowball sampling method was used, since many respondents indicated other potential candidates to complete the questionnaire, which was the same as that used in the period from May to September 2017.

3.2. Stage 2: Analysis of Information

The information obtained from the questionnaires was captured in an SPSS 24® software [69] database, due to its ease of use [70], where the columns represent all the observed variables or items and the lines represent cases or completed questionnaires. The database was refined to remove extreme values and missing values, which were replaced by the median for each item, since the evaluation scale used was ordinal. A value was considered extreme if, on standardisation, it had an absolute value greater than four. In the same way, if a questionnaire contained more than 10% of items without a response, it was rejected [71].

Once the database was refined, the sample was analysed using the demographic information obtained, where cross tables were created to understand the distribution. In the same way, a descriptive analysis of the items included in the latent variables was carried out, with the aim of identifying univariate trends, where the median was used as a measure of the central trend and the interquartile range was used as a measure of dispersion.

It should be noted that the variable *Investment in human resources* integrated two latent variables at the same time, *Education and training* and *Incentives*, so that the model presented is a second-order model. To validate the items in each of the latent variables, several indices were used, as proposed by Kock [72]. These were as follows:

- For parametric predictive validity, R-squared and adjusted R-squared were used, expecting values higher than 0.02, while for non-parametric predictive validity, Q-squared was used, with values expected to be similar to those of R-squared.

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- For internal validity, Cronbach's alpha and the composite reliability index were used, accepting values higher than 0.7.
- For convergent validity, average variance extracted (AVE) was used, accepting values higher than 0.5.
- For measuring collinearity, variance inflation factors were used, accepting values lower than 3.3.

The model was evaluated using WarpPLS v.5® software [73] with a confidence level of 95%, based on partial least squares algorithms, which is widely recommended for small samples with normality problems in the data or when the evaluation scale is ordinal, as was the case here. This technique has been used previously in various research studies to relate latent variables; García-Alcaraz et al. [74], for example, use it to relate the impact of the flexibility of supply chains on wine producers' operational performance, while Boon Sin, Zailani, Iranmanesh and Ramayah [59] use it to evaluate the effect of SS-related activities on companies' performance.

Although the latent variables were properly validated, it was also necessary to validate the structural equation model as a whole and the following indexes built into the WarpPLS v.5 software [73] were therefore used, as proposed by Kock [72]:

- For predictive validity, Average R-Squared (ARS) and Average Adjusted R-Squared (AARS) were used, associated with a *p*-value that must be less than 0.05.
- For measuring the collinearity between the latent variables, the average variance inflation factor (AVIF) and the average full collinearity VIF (AFVIF) were used, which must have values less than 3.3.
- For measuring the fitness of the data obtained for the model proposed, the Tenenhaus Goodness of Fit (GoF) index was used, which must have values greater than 0.36.

To validate the hypotheses set out in Figure 1, the direct effects of one latent variable on another were estimated, in order to obtain a β value as a measure of dependency between them, which is a standardised value. The null hypothesis that $\beta = 0$ versus the alternative hypothesis that $\beta \neq 0$ was tested with a confidence level of 95%. In the same way, the indirect effects existing between the latent variables through mediating variables were obtained and, finally, the total effects were obtained, representing the sum of the direct effects and the indirect effects [75].

In the proposed model, there are three latent dependent variables with an associated value of R-squared as a measure of the variance explained by the independent latent variables. This value is therefore broken down in the size of the effects to measure the contribution of each of the dependent variables to the value of R-squared, which allows quantification of the variables which are most important or which have the greatest explanatory power.

4. Results

After three months of administering the questionnaire, 301 valid cases were obtained, after some were rejected for exceeding the maximum number of missing values. The results of the analysis of the information and the validation of the hypotheses in the model are described below.

4.1. The Sample

Table 1 shows information from the surveyed sample. Only 287 of the 301 responded to the question on their industrial sector and certification in SS. The most represented sectors were the automotive and electrical industries, with 179 in the first sector and 32 in the second, representing 73.5% of the total sample. It is worth mentioning briefly that 155 respondents had been certified for one to two years, 71 for two to five years, 40 for five to ten, and finally, 30 had been certified for more than 10 years, while five did not declare how long they had been certified.

Table 1. Sample description.

Certification	Aeronautic	Electric	Automotive	Electronic	Medical	Other
Champion	0	2	6	0	0	2
Master Black Belt	2	5	33	5	0	5
Black Belt	3	16	45	9	4	9
Green Belt	1	5	33	2	8	10
Yellow Belt	1	4	62	7	4	4

Figure 2 illustrates the certification in SS for responders. It is observed that eighty-six persons have the Black Belt certification, but only ten were Champions. In addition, Figure 3 illustrates the main industrial sectors.

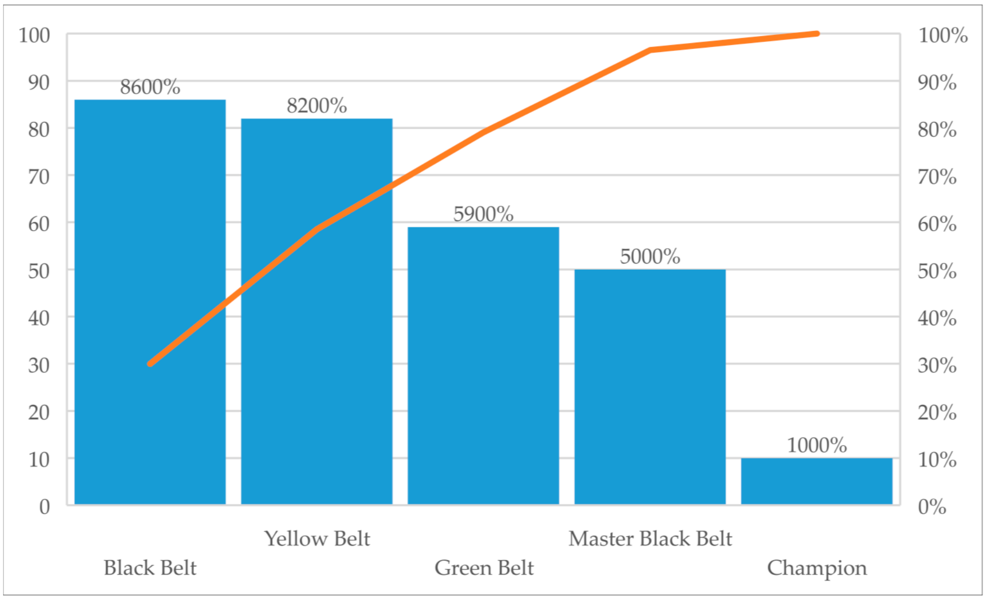

Figure 2. Certification in SS in surveyed persons.

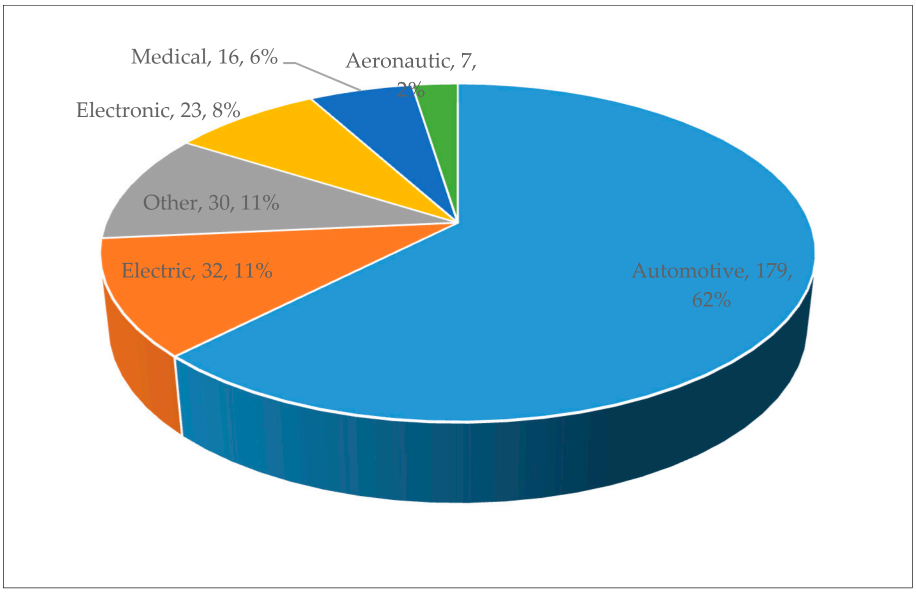

Figure 3. Industrial sector surveyed.

4.2. Descriptive Analysis of the Sample

Table 2 shows the descriptive analysis of the items integrated into the latent variables. It should be remembered that the latent variable *Investment in human resources* comprises two others, education and training and incentives. The items in each of the latent variables are sorted from highest to lowest according to the value of the median.

Table 2. Descriptive analysis of the sample.

Acronym	Item	Median	IR
MC3	Management encourages interdepartmental cooperation in planning six sigma projects	3.59	1.62
MC5	Management assigns the appropriate personnel for each project	3.53	1.6
MC4	Management requests reports on the progress of projects in each department	3.52	1.58
MC2	Management encourages knowledge transfer across different departments and the organisational structure	3.44	1.41
MC1	Management regularly reviews the progress of six sigma projects	3.24	1.14
IS5	Department heads review clients' demands and complaints before creating an six sigma project	3.99	2.18
IS4	Improvement teams are aware of clients' requirements	3.95	2.25
IS1	There is an organisational structure that supports six sigma including Black Belts (BBs), Green Belts (GBs) and Yellow Belts (YBs)	3.79	2.01
IS2	Meetings are held between six sigma project leaders and project team members to enable monitoring	3.73	1.94
IS3	Six Sigma projects are related to clients' demands	3.72	1.81
ET4	The workload is adjusted to allow time for education and training	3.67	1.84
ET3	Black Belts (BBs) and Green Belts (GBs) are involved in the analysis of problems associated with the six sigma project	3.66	1.81
ET5	Materials and software are provided for analysing the information	3.62	1.67
ET2	Black belts (BBs) and Green Belts (GBs) are assigned to advise on six sigma projects	3.42	1.5
ER1	There is a regular training schedule	3.24	1.16
IN3	Project outcomes are considered in career performance and impact on the income of project members	3.44	1.52
IN2	Regular awards are presented for the best six sigma projects	3.26	1.14
IN4	The abandonment of an six sigma project affects promotion to higher positions	3.14	1.05
IN1	Award ceremonies are held for certification as Black belts (BBs) and Green Belts (GBs), etc.	3.12	0.95
IN5	The outcomes of a six sigma project affect annual bonuses or salary increases at year end	3.06	0.78
ECB1	There are savings in production costs	3.99	2.29
ECB5	There is reduced wastage	3.99	2.34
ECB2	A competitive advantage is created for the company	3.91	2.3
ECB4	There are increased sales	3.87	2.12
ECB3	There are increased returns on investment	3.81	2.08

Based on the results of univariate analysis, it can be seen that the activity most representative of management commitment is promoting interdepartmental cooperation in planning SS projects. Nevertheless, there is an area of opportunity in the monitoring of these projects, as this item is the lowest. Likewise, in the section corresponding to economic profits, it can be seen that all items have

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very similar values and are the highest, indicating that SS projects do enable savings in production costs and a reduction in wastage; however, these are the items with the highest values in the interquartile range, indicating that there is only a moderate consensus. The results from the other latent variables can be interpreted similarly.

4.3. Data Validation

Table 3 shows the validation indices for the latent variables. According to this information, it can be seen that there is sufficient parametric predictive validity, since the values of R-squared and adjusted R-squared are higher than 0.02, the minimum acceptable value; in addition, the values of Q-squared in all the variables are positive and similar to R-squared, indicating that there is also non-parametric predictive validity. In the same way, the internal validity is adequate because the composite reliability index and Cronbach's alpha are greater than 0.7.

Table 3. Validation indexes.

Index	*Managerial commitment*	*Implementation strategy*	*Economical benefits*	*Investment in human resources*
R^2-Squared		0.381	0.484	0.434
Adjusted R^2-Squared		0.379	0.481	0.430
Compose reliability	0.919	0.919	0.923	0.920
Cronbach's alpha	0.890	0.890	0.896	0.826
Average variance extracted	0.695	0.695	0.706	0.852
Variance inflation index	2.047	2.071	1.990	1.790
Q^2-Squared		0.382	0.486	0.436

It can also be seen that the average variance extracted is greater than 0.5 for all variables, confirming that there is convergent validity and, finally, it can be concluded that there are no collinearity problems, since the variance inflation factors are less than 3.3, the maximum permitted value. On the basis of this information, it was concluded that the latent variables can be integrated into the model and the corresponding analysis could be performed.

4.4. Structural Equation Model

The variables were integrated into the model and run through WarpPLS software [73]. The validity indices for the model are shown below and the evaluated model appears in Figure 4:

- Average path coefficient (APC) = 0.425, $p < 0.001$
- Average R-squared (ARS) = 0.433, $p < 0.001$
- Average adjusted R-squared (AARS) = 0.430, $p < 0.001$
- Average block VIF (AVIF) = 1.514, acceptable if ≤ 5, ideally ≤ 3.3
- Average full collinearity VIF (AFVIF) = 1.974, acceptable if ≤ 5, ideally ≤ 3.3
- Tenenhaus GoF (GoF) = 0.565, small ≥ 0.1, medium ≥ 0.25, large ≥ 0.36

According to the information above, and considering the *p*-values and that these are lower than 0.05, it can be concluded that the relationships between the latent variables are statistically significant (see APC value) and that there is sufficient predictive validity in the latent dependent variables (see ARS and AARS). Similarly, there are no collinearity problems between the latent variables in the model, since the AFVIF and AVIF indices are lower than 3.3. It can also be seen that the data adequately fits the model (see GoF), since its value is greater than 0.36.

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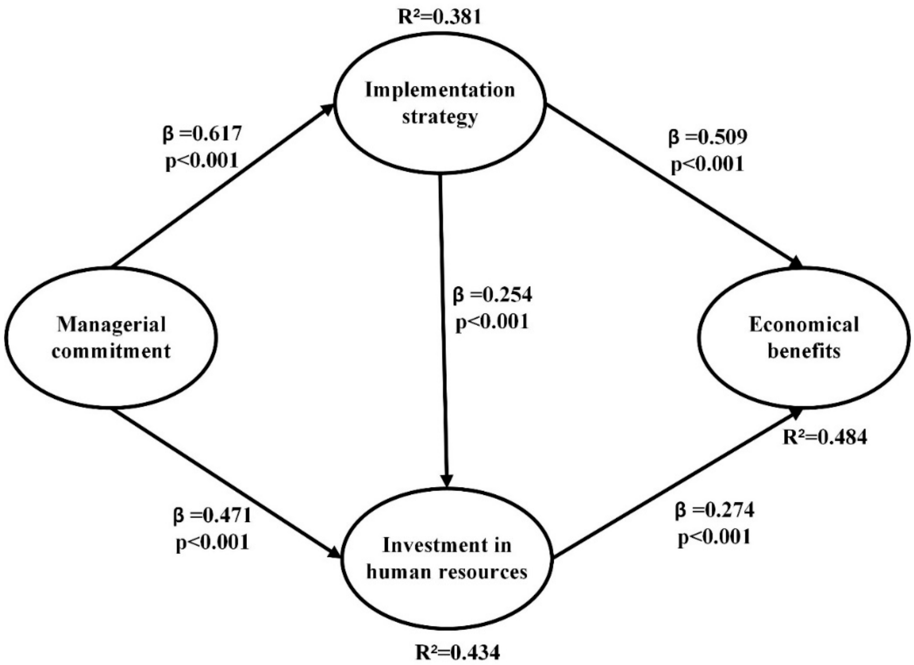

Figure 4. Evaluated model.

4.4.1. Direct Effects

The direct effects allow conclusions to be drawn in relation to the initial hypotheses and, given the values of the β coefficients and the associated *p*-values, the following can be concluded.

Hypothesis 1 (H1). There is sufficient statistical evidence to state that Managerial commitment to SS projects has a direct and positive effect on the Implementation strategy for this philosophy, since when the first latent variable increases its standard deviation by one unit, the second increases by 0.617 units.

Hypothesis 2 (H2). There is sufficient statistical evidence to state that Managerial commitment to SS projects has a direct and positive effect on Investment in human resources, such as education and incentives, since when the first latent variable increases its standard deviation by one unit, the second increases by 0.471 units.

Hypothesis 3 (H3). There is sufficient statistical evidence to state that the SS Implementation strategy has a direct and positive effect on Investment in human resources associated with education, incentives and rewards, since when the first latent variable increases its standard deviation by one unit, the second increases by 0.254 units.

Hypothesis 4 (H4). There is sufficient statistical evidence to state that the SS Implementation strategy has a direct and positive effect on the Economical benefits gained, since when the first latent variable increases its standard deviation by one unit, the second increases by 0.509 units.

Hypothesis 5 (H5). There is sufficient statistical evidence to state that Investment in human resources during the implementation of SS has a direct and positive effect on the Economical benefits gained by the company, since when the first latent variable increases its standard deviation by one unit, the second increases by 0.274 units.

4.4.2. Size of Effects

As can be seen in Figure 4, the variable *Investment in human resources* is 43.4% explained by two independent latent variables, since R^2 = 0.434. However, by breaking down the explained variance in the variable, it can be seen that *Managerial commitment* explains 29.6% and *Implementation strategy* explains 13.8% of the variance, which leads to the conclusion that the first variable is more important, given that it has greater explanatory power; in other words, managers must be committed to SS philosophy and invest in employees' education, training and performance-based rewards through incentives.

Likewise, the variable *Economical benefits* is 48.4% explained by two independent latent variables, since $R^2 = 0.484$. From this total, the SS *Implementation strategy* explains 33.4% and *Investment in human resources* explains 15.0% of the variance, which leads to the conclusion that the first variable is more important in ensuring the company's financial performance and the *Economical benefits*, since it has greater explanatory power, meaning that managers should focus on designing appropriate SS implementation plans as well as the needs of clients.

4.4.3. Sum of Indirect Effects

The direct effects allow validation of the hypotheses set out in Figure 1. Sometimes, however, the indirect effect is of greater importance due to its scale and the variables involved. In Figure 4, it can be seen that the variables *Investment in human resources* and *Economical benefits* have indirect effects through other mediating variables. These results are shown in Table 4, where it can be seen that they are all statistically significant.

Table 4. Sum of indirect effects.

To	From	
	Managerial commitment	***Implementation strategy***
Economical benefits	β = 0.486 ($p < 0.001$) ES = 0.282	β = 0.069 ($p < 0.001$) ES = 0.046
Investment in human resources	β = 0.157 ($p < 0.001$) ES = 0.098	

As can be seen in Figures 1 and 2, *Managerial commitment* is not directly related to *Economical benefits*, given that many other variables should be present in order to analyse their relationship; there is no point in there being a strong commitment from management if there are no plans or programmes aimed at improving quality and meeting clients' needs by means of SS (*Implementation strategy*), or if existing personnel are not involved by means of education and incentives (*Investment in human resources*). It can be seen that the indirect effect between *Managerial commitment* and *Economical benefits* is 0.486, explaining up to 28.2% of its variability, which indicates that managers should focus on gaining increased financial revenue when implementing philosophies applied to production systems, since this is sought by investors; however, this should go hand-in-hand with an appropriate *Implementation strategy* that includes human resources and that values and rewards their efforts.

4.4.4. Total Effects

The total effects represent the sum of the direct and indirect effects, as shown in Table 5, with their respective *p*-values for testing statistical significance and the amount of variance that they explain. It can be seen that the most significant effects correspond to the relationship between *Management commitment* and *Investment in human resources* (which includes one direct and one indirect effect through *Implementation strategy*), as well as *Implementation strategy* (which has only one direct effect). It is also important to point out the direct effect of *Implementation strategy* on *Economical benefits* (which includes one direct and one indirect effect through *Investment in human resources*), since its value is also high.

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Table 5. Total effects.

To	From		
	Managerial commitment	*Implementation strategy*	*Investment in human resources*
Economical benefits	β = 0.617 ($p < 0.001$) ES = 0.381		
Investment in human resources	β = 0.486 ($p < 0.001$) ES = 0.282	β = 0.578 ($p < 0.001$) ES = 0.380	β = 0.274 ($p < 0.001$) ES = 0.150
Investment in human resources	β = 0.627 ($p < 0.001$) ES = 0.394	β = 0.254 ($p < 0.001$) ES = 0.138	

5. Discussion and Industrial Implications

SS is a production philosophy which, despite having been introduced in American companies over thirty years ago, is still applicable today in industrial systems. It is a tool used for ensuring quality and, far from going out of fashion; its scope has increased due to aspects associated with market globalization and the customization of products and services required by clients.

Nevertheless, in order to obtain the benefits that it can offer, SS entails a number of factors as *Managerial commitment*, *Implementation strategy* and *Investment in human resources*. The relationship between these variables is widely described in other articles, but the contribution of this research is that it quantifies through a rigorous statistical analysis, the relationship and proposes measures of dependence among them. These measures of dependency and explanatory capacity among the variables allow decision-makers and responsible persons to focus the attention on those that are most important, ignoring trivial variables. SS is also very associated to sustainability and environmental management systems, both issues directly affected by *Investment in human resources*, as Daily and Huang [68] and Ehnert [67] indicate. Also, recent researches associate SS with sustainability, as for example, de Freitas et al. [7] that verify how Lean Six Sigma (LSS) could influence the organizational sustainability through their projects and Swain et al. [8] indicate that the growing importance of quality management and leadership and their impact to business sustainability is a current research area for both academicians and practitioners and findings in this report are contributing to that research gap.

Our findings indicate that *Managerial commitment* is required to design an *Implementation strategy* for SS, and only in this way is it possible to guarantee flexible, robust and efficient production processes, as suggested by Andersson, Hilletofth, Manfredsson and Hilmola [43]. While this *Implementation strategy* does not need to be permanent, senior management should ensure that it is dynamic and that it has the necessary adjustments to suit clients' needs. According to Drohomeretski, Gouvea da Costa, Pinheiro de Lima and Garbuio [41], it should be based on daily operations and activities that are proven to be capable of solving problems, and there must, therefore, be a feedback process in place for sharing experiences gained when applying SS on production lines. The relationship between *Managerial commitment* and *Implementation strategy* is demonstrated statistically in this study through the hypothesis H1.

Nevertheless, while SS involves various concepts, assuming that it is a philosophy, it requires the integration of human resources to ensure success and not only *management commitment*. Consequently, the hypothesis H2 relates these two variables, where a significant direct relationship is demonstrated, as well as an indirect relationship through the *Implementation strategy*. In other words, senior management should integrate education and training programmes in order to ensure that members of improvement teams can analyse the information obtained and that they are able to make decisions based on a reliable statistical basis. In this vein, Coleman [76] suggests that the support of experts in statistics is necessary in the initial stages of implementation. The results of this research are consistent with those of Kavčič and Gošnik [48], who consider that education is the basis for SS and many other production philosophies.

Another investment that should be managed by senior management is the system of bonuses and incentives offered to participants in SS projects who obtain satisfactory results, and this is, therefore, another scheme to be incorporated into the *Implementation strategy.* In other words, to ensure that SS is successful, reward schemes should be designed to keep workers motivated to continue working on SS projects and to share the knowledge generated between colleagues across departments. Failure to integrate a reward scheme can be the cause of multiple withdrawals and dropouts in SS projects, and Arumugam, Antony and Linderman [50], therefore, recommend studying their effect and impact. While Sabry [77] indicates that incentives are a minor CSF, it is recommended that cultural factors be analysed in order to understand the type of rewards that human resources value within each specific environment.

It has been assumed in this research that *Investment in human resources* depends on *Managerial commitment* and an appropriate SS *Implementation strategy*; however, when considering the β values, it is clear that there is greater dependence on the first variable and not on the second, since the value for the first relationship is 0.471 (H2), while the value for the second is 0.254 (H3). In other words, investments related to education, training and incentives involve a strategic decision corresponding to senior management, although they should be part of the strategy and the approach to SS projects (client-focused).

This research was based on the assumption that the *Economical benefits* obtained from SS depend on the *Implementation strategy* (H4) and the *Investment in human resources* (H5); however, when analysing the β values in each of the relationships, it can be concluded that economic income depends more on the *Implementation strategy* and the approach to SS projects, which this research assumes to be client-focused. Finally, if it were necessary to create a critical path based on the β values obtained in the relationships between latent variables based on their size, it could be concluded that the relationship is the following: *Managerial commitment* → *Implementation strategy* → *Economical benefits*. In other words, *Managerial commitment* is required to ensure a satisfactory approach to the *Implementation strategy* for SS projects and to therefore ensure that the *Economical benefits* reported in the literature are gained.

It is important to point out that, while in this research *Investment in human resources* has played a secondary role in the impact on the *Economical benefits* obtained from SS, it is an essential part of the *Implementation strategy*, since these human resources are the people who actually implement the plans and programmes created by senior management. As suggested by Kavčič and Gošnik [48], education and knowledge transfer generated during the various SS projects is what makes companies grow, and companies should therefore endeavour to preserve and share it. Moreover, in specific terms, investments made in education and training have been identified as critical success factors in various contexts, including industry in Brazil by Ribeiro de Jesus, Antony, Lepikson and Peixoto [23], in Malaysia by Habidin and Yusof [21] and in Italy by Brun [19], as well as in literature review [58], and it should not, therefore, be a factor neglected by managers, but should be properly integrated into the SS *Implementation strategy*.

6. Limitations and Future Research

This structural equation model was validated using information from companies in the Mexican manufacturing industry, whose geographical context could be seen as a limiting factor due mainly to cultural aspects, since SS is a philosophy linked to human factors. Nevertheless, the results of this research may serve to give a general idea of the relationships between the latent variables analysed.

Future research will seek to integrate other variables that have been identified during the course of this study, such as the management of knowledge generated within SS improvement teams, the communication and cooperation that takes place within them and the investment made in materials for SS education and training. In addition, a future research will be aimed to link the human resources abilities required for support sustainability and SS projects.

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Impact of human factor on flexibility and supply chain agility of La Rioja wineries

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Abstract: Human factors play an important role in the success of companies, especially in the performance of production systems. In this research paper, we propose a structural equation model that measures the impact of four human factors (knowledge, abilities, skills, and availability) on production process flexibility and supply chain agility in the wine industry of La Rioja, Spain. The results obtained indicate that these human factors have a direct and positive impact on production process flexibility and supply chain agility. Likewise, they can be indirectly linked to supply chain agility through production process flexibility. Based on these findings, this research encourages La Rioja wineries to jointly work with viticulture and enology programs of Spanish universities. This collaboration would enhance the impact of human factors on the wine industry, which would in turn allow wineries to rapidly and more effectively respond to customer needs.

ARTÍCULO ELIMINADO POR RESTRICCIONES DE DERECHOS DE AUTOR

SECCIÓN IV: MEMORIA DE LA TESIS

Resumen

La globalización ha obligado a las empresas a modificar sus cadenas de suministro y técnicas aplicadas para asegurar la calidad de sus productos, ya que se actualmente se tienen sistemas de producción distribuidos geográficamente. En esta tesis se reportan dos artículos que investigan los factores críticos de éxito de la metodología seis sigma en la industria maquiladora de Ciudad Juárez (México) y los beneficios que se obtienen de esta. Un tercer artículo reporta el efecto que tiene la flexibilidad y agilidad de la cadena de suministro en los índices de desempeño de ésta y se valida con información del sector vitivinícola de La Rioja (España). Se generan modelos de ecuaciones estructurales que relacionan factores críticos de éxito de seis sigma con sus beneficios, así como la flexibilidad y agilidad con el desempeño de la misma y esas relaciones constituyen una serie de hipótesis de investigación. Para validar las hipótesis, se ha obtenido información del sector maquiladora (México) y de la industria vitivinícola de La Rioja y se usan técnicas de mínimos cuadrados parciales. Los resultados indican que los gerentes de las industrias maquiladoras deben focalizarse sus esfuerzos en la formación de recursos humanos, proporcionar capacitación y entrenamiento a los grupos de mejora continua y realizar una adecuada administración del conocimiento generado en los proyectos, asimismo, los gerentes de las empresas vitivinícolas deben hacer un esfuerzo por generar flexibilidad a sus canales de distribución para generar agilidad en los productos que ofrecen a sus clientes.

Palabras clave: factores críticos, seis sigma, beneficios de seis sigma, cadena de suministro, agilidad y flexibilidad de cadena de suministro.

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Abstract

Globalization has forced companies to modify their supply chains and techniques to ensure the quality in their products, since currently the production systems are geographically distributed. In the present thesis, two articles that investigate the critical success factors from the Six Sigma methodology as a tool for quality assurance in the maquiladora industry of Ciudad Juárez (Mexico) and its obtained benefits are reported. In addition, a third article addresses the effect of the flexibility and agility in the supply chain on its performance indexes, which is validated with data from the wine sector of La Rioja (Spain). Also, Structural equation models are generated to relate critical success factors from six sigma along with their benefits, as well as their flexibility and agility with their performance, also these relationships among variables portray a series of research hypotheses. In order to validate these hypotheses, data has been obtained from the maquiladora sector (Mexico) as well as from the wine industry of La Rioja. In addition, partial least squares techniques are used for evaluating the models. Finally, the results indicate that managers in maquiladora industries should focus their efforts on human resources training, such as, provide training to groups who are operating continuous improvement, as well as support an adequate knowledge management generated in projects, similarly, managers in wine sectors must make an effort to achieve flexibility in their distribution channels to generate agility in the products that are offered to customers.

Key words: critical factors, six sigma, six sigma benefits, supply chain, agility and supply chain flexibility.

Modelos causales para la implementación de herramientas de manufactura esbelta y cadena de suministro

Introducción general

En esta sección se realizan una serie de definiciones y conceptos encaminados a definir el contexto en el cual se realiza la investigación, se plantean el problema de investigación y los objetivos de la misma.

La Globalización

La globalización es el medio por el cual ha evolucionado la integración de los países en diferentes ámbitos, tales como lo político, económico, social, cultural y tecnológico (van Neuss, 2018). Lo anterior conlleva a que dichos países se encuentren asociados para la generación de bienes y servicios, lo que ha traído como consecuencia una modificación en los sistemas de producción y de los mercados en los que se consumen dichos productos. Así, por ejemplo, hoy es muy común que, para generar un producto, ciertos componentes se fabriquen en un país y finalmente se ensamblen en otro (Prashantham, Eranova, & Couper, 2018), tal como ocurre en los sistemas producción del Airbus, donde diferentes países de la Unión Europea se integran en una sola empresa y se especializan en ciertos componentes.

Lógicamente, la globalización conlleva a una serie de ventajas para algunos países, tales como la circulación de bienes y productos importados que son caros de producir en una región, hay un aumento de inversiones extranjeras, se potencia el área de comercio internacional y se mejora el superávit en la balanza comercial, se propician mejores relaciones con otros países y se genera un intercambio cultural y tecnológico (Elsahn & Benson-Rea, 2018).

Esa globalización está enfocada a aprovechar los recursos, capacidades y habilidades existentes en diferentes países, por ejemplo, el bajo costo de la mano de obra de ciertas regiones, el nivel y avance tecnológico de otros y las capacidades de consumo, facilidades arancelarias y poder adquisitivo de otras. Esa globalización genera cadenas de suministro complejas en la que los socios y sus sistemas de producción están distribuidos en diferentes continentes (X. Zhang, Huang, & Wan, 2018), donde se integran centros de producción y centros de distribución alrededor del mundo, dependiendo de las necesidades que tengan las empresas.

La industria maquiladora

Una de las respuestas más frecuentes de las empresas transnacionales para enfrentar el proceso de globalización, consiste en crear centros de producción en otros países, con la finalidad de mejorar la proximidad que tienen con los clientes o consumidores finales (Hadjimarcou, Brouthers, McNicol, & Michie, 2013). Comúnmente a esas empresas en América Latina se les denomina maquiladoras, las cuales importan materiales de otros países sin pagar aranceles o a tasas preferenciales; sin embargo, se caracterizan por comercializar en el país de origen de la materia prima y distinto al de ensamble. Es decir, las maquiladoras son centros de producción que reciben la materia prima que entra como una importación, la procesan y ensamblan en un producto final, mismo que después se exporta a otros países (Sargent & Matthews, 2008). Específicamente, en México se han establecido muchas empresas americanas y europeas con la finalidad de aprovechar el costo bajo de la mano de obra y la proximidad a los Estados Unidos de América, uno de los mercados internacionales más grandes.

De acuerdo a lo anterior, se puede decir que una maquiladora generalmente es una empresa de inversión extranjera que se establece en una región (Hadjimarcou et al., 2013). Ese término se ha originado en México, país en el que actualmente existen 5089 empresas a nivel nacional, de los cuales 512 se encuentran en el estado de Chihuahua y más específicamente, 335 se encuentran establecidas en Ciudad Juárez, lo que indica que en esa región se encuentra establecido el 6.58 del total nacional y el 65.43% del total estatal (INEGI, 2018). En Ciudad Juárez ese sector industrial representa el 69% de la mano de obra económicamente activa, que encuentra laborando en 22 parques industriales, lo que representa a 292,053 empleos directos en enero de 2018. Asimismo, ese sector ha sido capaz de generar 36,396 millones de dólares en exportaciones en el periodo de enero a noviembre de 2017.

Los principales subsectores que se encuentran en la industria maquiladora son el automotriz con 29%, electrónico con 27%, plásticos/metales con 10%, empaques con 9%, medico con 6%, call centers con 3% y otros con 16%, los cuales son ampliamente reconocidos por tener un nivel tecnológico alto y contar con tecnología de punta en sus procesos de producción (INEGI, 2018). Sin embargo, con la llegada de esas empresas también se han adoptado nuevas técnicas, metodologías y herramientas enfocadas al uso óptimo de los recursos, tales como seis sigma y manufactura esbelta (Ocampo, Hernández-Matías, & Vizán, 2017).

En la Figura 4.1 se ilustra la casa de la manufactura esbelta, la cual está integrada por muchas herramientas que le dan soporte y algunas de ellas tienen un rol encaminado a darle a la empresa una estabilidad operativa, mientras que otras se refieren al flujo de los materiales y otros a la calidad.

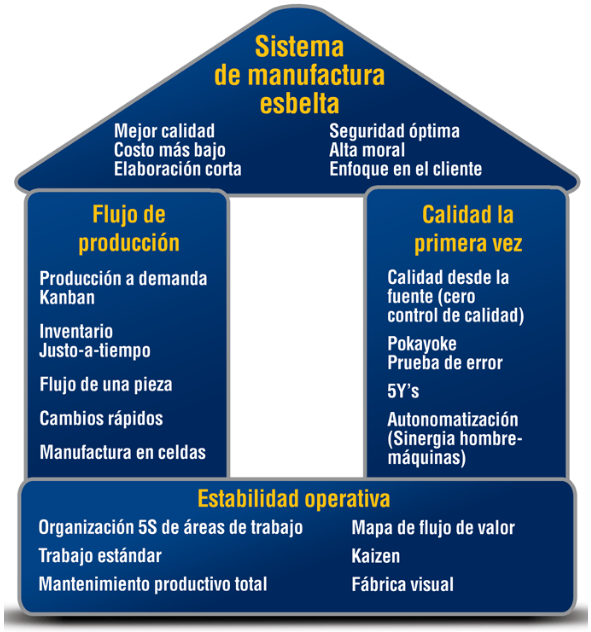

Figura 4.1 Las herramientas de manufactura esbelta

Sin embargo, esas técnicas aplicadas a los sistemas de producción han evolucionado rápidamente y en la actualidad es muy común escuchar hablar de lean seis sigma (LSS), donde SS se ha integrado a manufactura esbelta para poder garantizar la calidad. En la Figura 4.2 se ilustra la integración de esas dos herramientas en una sola, donde se hace énfasis en dos aspectos importantes: Mejorar la calidad del producto final y reducir costos, lo que lleva al estudio de seis sigma para atender el primer rubro y al estudio de las cadenas de suministro y transporte, ya que en las empresas maquiladoras este rubro es uno de los más altos e incluso, autores como Zhou, Guo, and Zhou (2018) mencionan que la logística y sus componentes pueden representar hasta el 70% del costo del producto, lo que hace a ésta una área de investigación con muchas oportunidades de mejora.

Seis sigma

Aunque existen muchas definiciones en relación al concepto de seis sigma (SS), ésta es considerada una metodología de mejora de procesos de producción que tiene sus orígenes en la empresa Motorola y fue implementada por Bill Smith en la década de los 80. Su principal objetivo es la reducción de la variabilidad de los procesos, lo que permite reducir o eliminar los defectos o fallos en los productos que son entregados al cliente (Mustafa & Jamaluddin, 2017). Tal como su nombre lo indica, SS busca tener un máximo de 3.4 defectos por millón de eventos u oportunidades y en ese sentido, se entiende como defecto a cualquier evento o característica en un producto o servicio que no cumple con las especificaciones establecidas por el cliente (Gaikwad, Teli, Majali, & Bhushi, 2016).

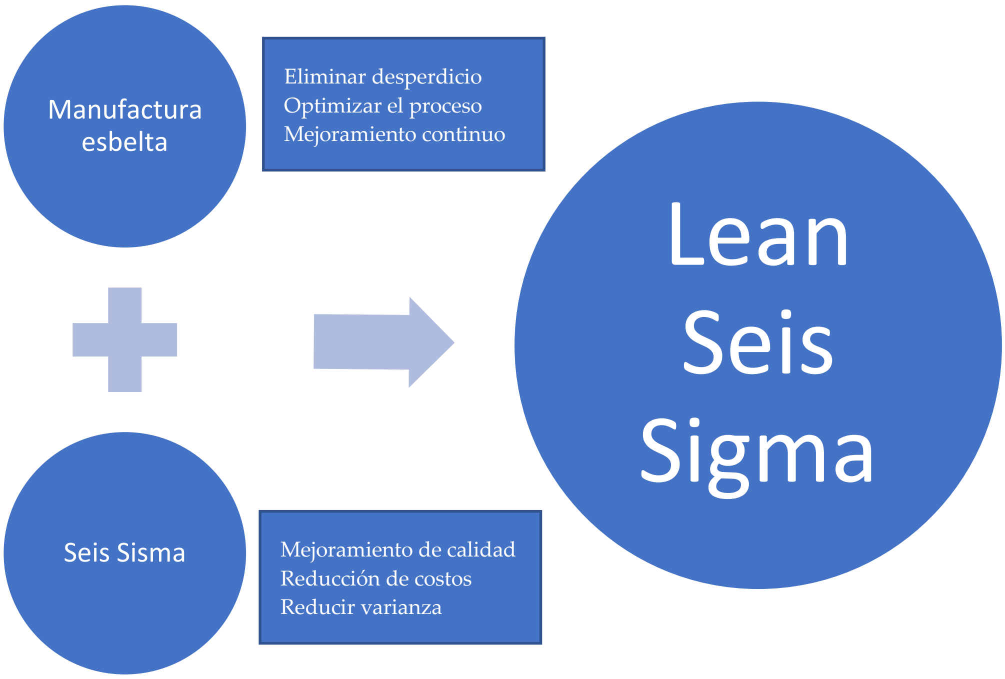

Figura 4.2 Lean seis sigma – Integración de conceptos

Por lo anterior, se concluye que SS es uno de los pilares del aseguramiento de la calidad, ya que busca establecer procesos que están totalmente estandarizados y que disminuye los errores en los productos (Juahir et al., 2017). Asimismo, se puede decir que SS también tiene un concepto estadístico, ya que sigma se representa por σ y representa a la desviación estándar de una métrica o característica de los productos. Una alta variabilidad representa un valor de sigma muy alto y, por lo tanto, muchos errores en la característica del producto, mientras que un valor de sigma igual a cero significa que todos los productos tienen el mismo valor de la métrica y que el proceso está estandarizado.

SS hace uso de muchas herramientas estadísticas para caracterizar e identificar la situación que tienen los procesos de producción y en base a ello tomar decisiones encaminadas a disminuir la variabilidad (que es considerado el problema principal), por lo que sigue una serie de pasos o actividades que deben realizarse de manera secuenciada para lograr el éxito (Alhuraish, Robledo, & Kobi, 2017), mismos que se definen a continuación.

Los pasos de seis sigma

Dado que SS es considerada una metodología aplicada a los sistemas de producción, su proceso de implementación sigue una serie de pasos o etapas, a la que se conoce como proceso DMAIC (Por sus siglas en inglés: Define - Measure - Analyze - Improve - Control). Cada una de esos pasos se discuten a continuación brevemente y se toman como base los conceptos de Diego Tlapa, Limon, García-Alcaraz, Baez, and Sánchez (2016) y las principales herramientas recomendadas por Marzagão and Carvalho (2016a) y otros autores:

Definir. En esta etapa se busca conocer el estado que tiene el proceso de producción en el que se presenta el problema de variabilidad. De la misma manera, se establecen objetivos alcanzables, se definen las limitantes, se asignan recursos y se establecen los puntos críticos que pueden tenerse. En esta esta etapa se usan principalmente herramientas como diagramas matriciales, mapas de los procesos en los que se presenta en problema y diagramas de Pareto que ayudan a obtener prioridades en los problemas a resolver.

Medir. Para poder monitorear un proceso y conocer el estado que éste tiene es necesario identificar a las variables críticas del proceso y el nivel que éstas tienen. A esta etapa también se le puede llamar parametrización del problema y es importante que se integren todas las variables que afectan al proceso. Las principales herramientas de apoyo en esta etapa son (Laureani & Antony, 2017; Lerner, 2016): diagramas de flujo de la información y los materiales, mapas de proceso, técnicas de muestreo para censado de variables, análisis de modo y efecto de fallos (AMEF) para buscar causas raíz, despliegue de la función de calidad (QFD) como método de diseño de productos y servicios, modelo de Kano para la clasificación de las preferencias del cliente, eficiencia general de los equipos (OEE) para conocer los niveles de disponibilidad de los mismos y nivel sigma que tiene el proceso actualmente.

Analizar. Consiste en analizar la información recolectada en la etapa de medición mediante técnicas estadísticas que ayuden identificar una causa y un efecto, así como su relación y nivel de dependencia. Esta etapa está enfocada a relacionar las variables o parámetros y las principales herramientas que dan soporte son (Laureani & Antony, 2018; Lerner, 2016): mapas de valor del proceso productivo, diagramas de flujo de materiales y secuencias de las actividades, diagramas de recorrido de los materiales, gráficas de control estadístico, gráficos de pescado de las cuatro M, análisis del Cpk del proceso y análisis de modo y efecto de fallos (AMEF).

Mejorar. Del análisis de la información realizada anteriormente, deben tomarse decisiones relacionadas al cómo se realizarán las mejoras, las cuales pueden ser modificaciones a los sistemas ya existentes, o bien, rediseñarse nuevos procesos. En esta etapa es importante que se realice una integración de los recursos humanos que tienen relación con el proceso que se va a mejorar, ya que son éstos los que realmente conocen el sistema productivo y pueden aportar opiniones que son valiosas en el proceso de mejora. Las principales herramientas que dan soporte en esta etapa son (Laureani & Antony, 2018; Lerner, 2016): 5's, ingeniería de métodos (estudios de tiempos y movimientos), balance de líneas de producción, mantenimiento productivo total (TPM, por sus siglas en inglés), cambio de matriz en menos de 10 minutos (SMED), sistemas Kanban y Andon.

Controlar. De nada sirve un sistema de mejora establecido si no se controla, se mantiene y se vuelve a mejorar de manera continua, tal como lo indica Surange (2015). Es de vital importancia que las mejoras en el proceso se mantengan durante cierto periodo de tiempo, pero también debe ser un reto mejorarlo después mediante un proceso incremental paulatino, donde metodologías como Kaizen o de mejoramiento continuo son vitales en esta etapa. De la misma manera, se deben seguir monitoreando los procesos mejorados para conocer el estatus que tiene y nuevamente iniciar en la etapa inicial de definir. Las principales herramientas que se usan en esta etapa son (Laureani & Antony, 2018; Lerner, 2016): los sistemas andon, las Procedimientos Operativos Estandarizados de Saneamiento (POES), lecciones en un punto (LUP) y sin lugar a duda, la capacitación de todos los involucrados.

En la Tabla 4.1 se ilustra un resumen de las principales actividades que se deben de realizar en cada una de las etapas anteriores, mismo que ha sido extraído de Kwak and Anbari (2006).

Tabla 4.1 Actividades en cada etapa de SS

Etapa de SS	Actividades
Definir	Definir los requisitos y expectativas del cliente Definir los límites del proyecto Definir el proceso y mapear el flujo de negocios
Medir	Medir el proceso para satisfacer las necesidades del cliente Desarrollar un plan de recopilación de datos del problema Recopilar y comparar datos para determinar problemas y deficiencias con estándares establecidos
Analizar	Analizar las causas de los defectos y las fuentes de variación Determinar las variaciones en el proceso

	Priorizar las oportunidades de mejora futura
Mejorar	Mejorar el proceso para eliminar variaciones Desarrollar alternativas creativas e implementar un plan mejorado
Control	Controlar las variaciones del proceso para cumplir con los requisitos del cliente Desarrollar una estrategia para monitorear y controlar la mejora proceso Implementar las mejoras desde un punto de vista de sistemas

La estructura humana para seis sigma

SS como filosofía aplicada a los sistemas de producción requiere del apoyo y soporte de las personas o recursos humanos, las cuales juegan un rol en el éxito de la misma. En función del rol y nivel de conocimientos que tengan para la aplicación de SS, las estructura es la siguiente (Laureani & Antony, 2017):

1. Director Six Sigma: se refiere al líder o responsable de fijar los objetivos del programa, define las estrategias que se deben seguir y los responsables de las actividades. De la misma manera, en compañía de un equipo multidisciplinario, se encarga de seleccionar los proyectos de SS que tienen mayor impacto para la empresa y que presentan mayor viabilidad. Finalmente, Mustafa and Jamaluddin (2017) mencionan que el Director de SS es el responsable de realizar la difusión de los resultados alcanzados por los diferentes proyectos, propone estrategias de mejora para los mismos, analiza por qué no se han alcanzado los objetivos planeados y gestiona los recursos requeridos.
2. Altos directivos - Champions. En la estructura organizacional para SS, ellos son los directores de área y se encargan de la dirección estratégica que debe tener le programa y los proyectos. Son los responsables de la gestión de recursos ante el director de SS e informar a éstos sobre el avance de los proyectos, sus problemas de ejecución y de dar soporte a los grupos de mejora. Los champions son los responsables de coordinar los proyectos de SS con los master black belts.
3. Master black belts. Es posible que en la estructura no existan y que la relación de los champions se realice de manera directa con los black belts. Generalmente son personas black belt que han sido entrenados en técnicas estadísticas avanzadas que son aplicadas en la solución de problemas, lo que indica que son personas que tienen amplia experiencia en la ejecución de SS en los sistemas productivos.
4. Black belts. Son expertos a nivel técnico, lo que indica que son los que ejecutan los proyectos de SS en los sistemas productivos y generalmente el porcentaje de tiempo dedicado a la mejora de procesos

es muy alto. Se puede decir que son los líderes de SS en las líneas de producción. Los black belts tienen la responsabilidad de difundir y mantener la cultura de SS y tienen una relación directa con los green belt, a quienes apoyan en sus proyectos proponiendo soluciones.

5. Green belts. Ellos son a veces considerados los recién iniciados en la filosofía SS, ya que su dedicación a la misma es de tiempo parcial, ya que tienen otras responsabilidades técnicas y operativas en el sistema productivo. Su participación es como líderes de proyectos en su área de trabajo.

En la Figura 4.3 se ilustra una estructura organizacional humana propuesta por Antony, Jiju Antony, Kumar, and Rae Cho (2007) después de realizar una revisión del estado del arte que tenía la técnica en empresas manufactureras de Inglaterra.

Figura 4.3 Estructura organizacional para SS

Fuente: Antony et al. (2007)

Los beneficios de SS

Aunque han sido muchas las empresas que han reportado beneficios al implementar SS en sus procesos de producción, fue Motorola la primera empresa en reportar que esta filosofía había sido integrada a sus programas de aseguramiento de la calidad, aunque las empresas japonesas habían sido las primeras en usarla. Poco tiempo después, otras empresas occidentales reportaron los resultados obtenidos al adaptar SS, tales como General Electric, Boeing, DuPont, Toshiba, Seagate, Allied Signal, Kodak, Honeywell, Texas Instruments, entre otras.

Afortunadamente, han sido muchos los académicos que se han esforzado por identificar los beneficios obtenidos y en la Tabla 4.2 se presenta un resumen de los mismos en los procesos de manufactura, la métrica que ha sido usada y los ahorros o beneficios económicos obtenidos, mismos que han sido reportados por Kwak and Anbari (2006).

Tabla 4.1 Principales beneficios obtenidos de seis sigma en sistemas de manufactura

Compañía/proyecto	Métrica/medida	Ahorro/beneficio
Motorola 1992	Nivel de defectos	Reducción de 150 veces el nivel de defectos
Raytheon/aircraft integration systems	Tiempo de inspección	Reducción del 88% medido en días
GE/Railcar leasing business	Tiempo de respuesta en talleres de reparación	Producción del 62% del tiempo
Allied signal (Honeywell)/laminates plant in South Carolina	Capacidad de tiempo de ciclo	Disminución de más del 50%
Allied signal (Honeywell)/bendix IQ brake pads	Tiempo de ciclo	Reducido de 18 meses a ocho meses
Hughes aircraft's missiles systems group/wave soldering operations	Calidad/productividad	Mejorada en un 1000% / mejorada en un 500%.
General electric	Financiero	2 billones de dólares en 1999
Motorola 1999	Financiero	15 billones de dólares en 11 años de aplicación
Dow chemical/rail delivery project	Financiero	Ahorro de $ 2.45 millones en gastos de capital
DuPont/Yerkes plant in New York (2000)	Financiero	Savings of more than $25 million
Telefónica de España 2001	Financiero	Ahorro e incremento en ingresos de 30 millones de euro en los primeros 10 meses
Texas instruments	Financiero	Ahorro de 600 millones
Johnson and Johnson	Financiero	Ahorro de 500 millones
Honeywell	Financiero	Ahorro de 1.2 billones de dólares

Sin embargo, los beneficios obtenidos por SS también han sido reportados en el sector de los servicios y en una investigación reportada por Antony et al. (2007), se observa que esta metodología es muy versátil y que puede ser llevada más allá del sector industrial, ya que resume un conjunto de beneficios en el sector salud, bancario, servicios financieros y otros misceláneos.

En relación al sector salud, se han reportado mejoras en los reclamos oportunos y reembolsos imprecisos de clientes, se ha simplificado la entrega de asistencia sanitaria, se ha reducido el inventario de equipos quirúrgicos, entre otros (Azis & Osada, 2013; de Koning, Verver, van den Heuvel, Bisgaard, & Does, 2006). Asimismo, en el sector de la construcción se reportan beneficios asociados al impacto de SS sobre la sustentabilidad organizacional (de Freitas, Costa, & Ferraz, 2017) y a los ahorros obtenidos a través del mejoramiento en la planeación de las actividades (Qayyum, Fahim, Jamaluddin, & Farooq, 2016).

Asimismo, se han reportado casos en el sector bancario y financiero en el que se reportan las ganancias obtenidas después de aplicar la metodología de SS en el análisis de deudores (Shafer & Moeller, 2012). Finalmente, es importante mencionar que esta metodología también ha sido empleada en proyectos de innovación, donde se han obtenido grandes beneficios (Parast, 2011). En la Tabla 4.3 se resume una lista en la que se describe el sector de servicios y los principales beneficios que se han obtenido.

Tabla 4.2 Beneficios en el sector de servicios

Sector	Medida	Beneficio
Salud (Buck, 2001; Cima et al., 2011; Thomerson, 2001)	Reducción en el costo de una radiografía	Incremento de un 33% en beneficio económico
	Errores de laboratorio	1.2 billones en ahorros
	Tiempo de espera del paciente	$600,000 de beneficio por año
Bancos (Reguera-Alvarado, Blanco-Oliver, & Martín-Ruiz, 2016; Salaheldin & Abdelwahab, 2009)	Quejas y nivel de satisfacción de los clientes	Incremento en un 10.4% en la satisfacción de los clientes. Reducción en un 24% en el número de quejas. Reducción en un 80% de llamadas telefónicas por quejas.
	Fallas en los procesos orientados al cliente	Incrementa la satisfacción del cliente. Incremento de la eficiencia del proceso. Reducción del tiempo de ciclo en más del 30%.
	Reducción en el número de tarjetas de crédito renovadas regresadas	Millones de dólares en ahorros. Incremento de la moral de los trabajadores.
Servicios financieros (Paşaoğlu, 2015)	Costos administrativos	Reducción de $75,000 por año aproximadamente
	Tiempo requerido para realizar transferencias	Ahorro de $700,000 por año
	Flujo de efectivo	Más de $350,000 en ahorros anuales
	Tiempo de entrega	Más de 1.5 millones de dólares ahorrados

Otros servicios y misceláneos (Westgard & Westgard, 2017)	Número de reclamos	Reducción de 109 reclamos a 55 por año
	Número de entregas retrasadas	Ahorros por $400,000 dólares al año
	Errores en reportes contables	Más de 1.2 millones de dólares ahorrados

Los factores críticos de éxito de SS

Dada la cantidad de beneficios obtenidos como consecuencia de una adecuada implementación de SS y que han sido reportados por muchas empresas y académicos, sobre todo en aspectos económicos, la metodología ha sido rápidamente adoptada por otras empresas (Raman, Basavaraj, Prakash, & Garg, 2017). Sin embargo, no siempre se han obtenido los mismos resultados en todas las empresas que han aplicado SS e incluso, algunas empresas han abandonado su implementación (Laureani & Antony, 2018). Algunos autores mencionan que existen muchos obstáculos para el proceso de implementación (Kwak & Anbari, 2006) y que para evitar eso, deben realizarse muchas actividades previas, a las que se ha denominado factores críticos de éxito, mismos que garantizan los beneficios reportados.

Afortunadamente, son muchos los casos en los que se han reportado listas de FCE para SS y a continuación se encuentra una relación de los más comunes, así como algunos de los autores que los han mencionado.

- Compromiso y apoyo de la alta gerencia (Alhuraish et al., 2017; Laureani & Antony, 2018; Mustafa & Jamaluddin, 2017).
- Educación y entrenamiento (Laureani & Antony, 2018; Psomas, 2016; Ribeiro de Jesus, Antony, Lepikson, & Peixoto, 2016).
- Comunicación (Alhuraish et al., 2017; Lande, Shrivastava, & Seth, 2016; Ribeiro de Jesus et al., 2016).
- Involucramiento de los empleados (Desai, Antony, & Patel, 2012; Habidin & Yusof, 2013; Ismyrlis & Moschidis, 2013).
- Cultura del cambio (Coronado & Antony, 2002; Desai et al., 2012; Habidin & Yusof, 2013).
- Entender las técnicas y herramientas de SS (Lande et al., 2016; Näslund, 2013; D. Tlapa, Limón, Baez, & Valles-Rosales, 2014).
- Habilidades, destrezas y experiencia (Brun, 2011; Desai et al., 2012; Revere, Kadipasaoglu, & Zalila, 2006).
- Vincular SS con el cliente (Lande et al., 2016; Laureani & Antony, 2018; Mustafa & Jamaluddin, 2017; D. Tlapa et al., 2014).

- Vincular SS con la estrategia de negocio (Desai et al., 2012; Ismyrlis & Moschidis, 2013; Revere et al., 2006).
- Vinculas SS con los proveedores (Hagspiel, 2018; Raman et al., 2017; Swain, Cao, & Gardner, 2018).
- Vincular SS con los recursos humanos en toda la empresa (Erdoğan & Canatan, 2015; Ribeiro de Jesus et al., 2016; Swain et al., 2018).
- Generar un sistema de recompensas (Brun, 2011; Fairul-Anwar & Mohd Amran, 2015; D. Tlapa et al., 2014).
- Habilitar la gestión de proyectos (Boon Sin, Zailani, Iranmanesh, & Ramayah, 2015; Parast, 2011; Tenera & Pinto, 2014).

De lo anterior se puede observar que al ser SS una metodología, ya que existe un gran enfoque a los recursos humanos, donde se observan aspectos asociados a ellos, tales como al liderazgo y compromiso de la alta gerencia, las habilidades y destrezas que éstos tengan, la comunicación que exista entre los diferentes niveles de la organización, al nivel de involucramiento de los empleados y los grupos de mejoramiento continua, al nivel de entendimiento que se tenga de las técnicas, entre otros. Lo anterior demuestra que SS debe su éxito al compromiso de los factores humanos y entonces es importante determinar cuáles de esos FCE de SS que pueden garantizar su éxito.

De la misma manera, se han realizado análisis comparativos entre países, ya que todos ellos pueden tener culturas diferentes y dado que SS es una filosofía atribuida a los recursos humanos, entonces se espera que esos FCE sean diferentes. En la Tabla 4.4 se listan algunos beneficios que han sido reportados por Lande et al. (2016), donde se mencionan los países en los que se han identificado, mismos que se encuentran ordenados según el número de citas que han tenido.

Tabla 4.3 Factores de éxito de SS por países

Factor	Brasil	Tailandia	Malasia	Reino Unido	Australia	India	Total
Aprendizaje organizacional	✓	✓		✓	✓	✓	5
Cultura de innovación	✓	✓		✓	✓	✓	5
Liderazgo y constancia	✓	✓	✓		✓	✓	5
Enfoque al cliente	✓	✓	✓			✓	4
Apoyo de la alta dirección		✓		✓	✓	✓	4
Entrenamiento		✓		✓	✓	✓	4

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Relaciones con proveedores			✓	✓	✓	✓	4
Administración basada en información	✓	✓				✓	3
Comunicación		✓			✓	✓	3
Relacionar SS al negocio				✓	✓	✓	3
Relacionar SS a los clientes				✓	✓	✓	3
Pensamiento sistémico	✓				✓		2
Conocimiento del mercado y clientes	✓					✓	2
Dirección estratégica		✓				✓	2
Reconocimiento y recompensas		✓				✓	2
Énfasis en equipos		✓				✓	2
Involucramiento de empleados		✓				✓	2
Soporte de TIC		✓			✓		2
Enfoque a resultados		✓	✓				2
Procedimientos de mejora			✓	✓			2
Entendimiento de SS				✓		✓	2
Selección de proyectos SS				✓		✓	2
Habilidades en administración de proyectos				✓		✓	2
Ligar la SS con los empleados				✓		✓	2
Visión del futuro	✓						1
Creación de Valor	✓						1
Valorar a las personas	✓						1
Desarrollo de asociaciones	✓						1
Compromiso de empleados		✓					1
Cambio de administración		✓					1

Contabilidad		✓					1
Monitoreo		✓					1
Calidad de la información y análisis			✓				1
Justo a tiempo			✓				1
Enfoque en métricas			✓				1
Redes con gobierno y academia					✓		1
Bechmarking						✓	1

La cadena de suministro

Una cadena de suministro es una red de socios integrados en un proceso de producción de manera directa o indirecta con la finalidad de satisfacer las necesidades de un cliente e incluye a los proveedores de materia prima en todos sus niveles, al fabricante que las transforma en sus líneas de producción y a los distribuidores que llevan un producto final al cliente (Avelar-Sosa, García-Alcaraz, Vergara-Villegas, Maldonado-Macías, & Alor-Hernández, 2015). Así pues, se puede decir que una cadena de suministro consta básicamente de tres componentes: el sistema de proveeduría, la transformación o manufactura y la distribución, por lo que puede decirse que comprende todos los eventos que cubren el ciclo de vida entero de un producto o servicio desde que es concebido como un diseño hasta que es consumido por un cliente (Spiliotopoulou, Boni, & Yadav, 2013; Yang, 2014).

La importancia del estudio de la cadena de suministro radica en que muchas de las actividades aquí desarrolladas no generan un valor añadido al producto, e incluso, algunos autores mencionan que hasta el 70% del costo de un producto puede deberse a aspectos asociados a la cadena de suministro en los que no se ha añadido valor (Zhou et al., 2018), pero sí un costo al producto final, ya que en estos tiempos de globalización, dichas cadenas de suministro tiene socios diferentes partes del mundo y se requiere la movilización de muchas de las partes y componentes, donde no se les añade valor pero si un costo. Asimismo, durante el transporte y movimiento de las materias primas y productos terminados, existe una alta probabilidad de dañarlos y tener mermas por ese concepto, además de que es muy frecuente que en esta etapa ocurran accidentes y de ahí la importancia del estudio de ésta (Sreedevi & Saranga, 2017).

En la Figura 4.4 se ilustra una cadena de suministro para un producto cualquiera, donde cada uno de los eslabones puede representar a uno de los socios en la misma. Obsérvese que todos empiezan con un proveedor de materias primas, tienen un proceso de producción, una distribución de producto terminado.

Figura 4.4 Cadena de suministro tradicional

La cadena de suministro (CS) tiene varias características que son deseadas con la finalidad de facilitar el proceso de entrega de productos terminados a los clientes, tales como la flexibilidad, la agilidad y la implementación de tecnologías de la información y la comunicación a lo largo de la misma. Esas características se estudian a continuación.

Flexibilidad de la cadena de suministro

Los clientes en la actualidad tienen necesidades cambiantes de manera frecuente y es por ello que el ciclo de vida de un nuevo producto es relativamente corto, ya que éste es fácilmente reemplazado por otro (Sreedevi & Saranga, 2017). De la misma manera, es muy frecuente que las cantidades demandadas por el cliente cambia de un día otro y por lo tanto, la flexibilidad de la cadena de suministro puede ser considerada como la capacidad que tiene de responder y adaptarse de manera rápida a las nuevas situaciones y condiciones que requiera el cliente, pero debe hacerse además con el menor costo, en el menor tiempo y con la menor pérdida de resultados o ingresos económicos para la empresa (Manders, Caniëls, & Ghijsen, 2016).

La flexibilidad de la cadena de suministro representa una ventaja competitiva para la empresa que es capaz de adaptarse, ya que permite anticiparse y adecuar su proceso de producción con diferentes alternativas para ofrecer un mismo producto (J. L. García-Alcaraz, Adarme-Jaimes, & Blanco-Fernández, 2016). Así, la flexibilidad se refiere a las diferentes formas y métodos con que una empresa puede responder a la demanda cambiante de su cliente (Fischer, Thomé, Scavarda, Hellingrath, & Martins, 2016). Este concepto conlleva a redefinir lo que tradicionalmente se entiende por flexibilidad, ya que usualmente el gerente de producción considera que su sistema es flexible si lo son sus máquinas; sin embargo, el concepto va mucho más allá y no solamente comprende al proceso de producción. Un concepto mejorado de flexibilidad tiene que ver con la capacidad de la empresa para poder predecir esos cambios de manera acertada y con el menor error posible, así como tener integrados proveedores que puedan ayudar a amortiguar los pedidos inesperados.

Sin embargo, Gong (2008) declara que las empresas siempre deben realizar un análisis económico para determinar el nivel de flexibilidad que tienen en sus cadenas de suministro, ya que de manera conceptual podría pensarse que altos niveles de flexibilidad son adecuados, sin embargo el costo de producción puede ser muy elevado. Ahora bien, también es cierto que no ofrecer esas diferentes alternativas a los clientes, puede traer como consecuencia la pérdida de éstos, lo que representa también una pérdida económica y financiera. Por lo tanto, siempre debe haber un balance entre la flexibilidad y el costo de esta.

Algunos otros autores enfocan su estudio en minimizar el riesgo de la cadena de suministro cuando no se tiene suficiente flexibilidad. Merschmann and Thonemann (2011) declaran que la flexibilidad se asocia directamente con el nivel de incertidumbre que tienen el flujo de materiales, información y recursos financieros, con el desempeño global de la empresa. Esa flexibilidad puede encontrarse en todos los niveles de la cadena de suministro, por lo que la empresa debe buscar tener esa característica en las relaciones con sus proveedores (Gosling, Purvis, & Naim, 2010), en su proceso de producción y en su sistema de distribución (Seebacher & Winkler, 2015).

Agilidad de la cadena de suministro

En párrafos anteriores se mencionaba que la flexibilidad se refiere a las diferentes formas en las que una empresa puede satisfacer las necesidades de su cliente. Sin embargo, también debe hacerlo de manera rápida y a eso se refiere la agilidad, la cual va más allá gracias a la capacidad de anticiparse a eventos futuros. La agilidad ya supone tener una visibilidad amplia de la cadena de suministro y poder compartir información de manera rápida y confiable con todos los demás socios de la misma. Así, los proveedores pueden identificar una entrega retrasada, determinar el estatus en que se encuentra un pedido y de esta manera tomar decisiones en tiempo real.

Sin embargo, ante los imprevistos que pudieran presentarse, se puede decir que la agilidad de la cadena de suministro es una consecuencia de la flexibilidad y es muy frecuente que esos dos conceptos se confundan. Actualmente existen muchos estudios que reportan la importancia que tiene la agilidad en la cadena de suministro; por ejemplo, Um (2017) realiza un estudio para determinar el impacto que tiene la agilidad en el desempeño de las empresas cuando se tiene un alto nivel de personalización del producto, por su parte Kim and Chai (2017) declara que es agilidad no debe ser propias del fabricante, sino que debe también exigírsele a los proveedores de éste, ya que son los responsables de entregar de manera eficiente las materias primas requeridas para satisfacer las órdenes de producción. Asimismo, J. L. García-Alcaraz et al. (2017) declaran que la inversión en capacitación y adquisición del conocimiento de los recursos humanos disponibles, es una actividad que la alta gerencia debe realizar de manera frecuente.

Finalmente, importante mencionar que en el estudio reportado por Chan, Ngai, and Moon (2017) se identifican varios tipos de flexibilidad es que puede tener un fabricante con sus socios para poder generar una agilidad en la cadena de suministro, también en su estudio Gligor, Holcomb, and Feizabadi (2016) indagan los diferentes antecedentes que debe de tener una empresa para poder garantizar la flexibilidad de su cadena de suministro y finalmente, Sangari, Razmi, and Zolfaghari (2015) desarrollan un marco teórico para determinar los factores críticos que pueden garantizar la agilidad.

También, Gligor, Esmark, and Holcomb (2015b) declaran que muchas veces las empresas se ven tentadas a incrementar su capacidad y agilidad; sin embargo, siempre debe realizarse un estudio económico, ya que la agilidad usualmente se asocia con inversiones en tecnologías de la información y la comunicación, mismas que pueden resultar caras. Un resumen de estudios en los que se asocia a los niveles de inversión en tecnologías avanzadas con la agilidad de la cadena de suministro puede consultarse en Ngai, Chau, and Chan (2011).

Problema de investigación

Actualmente se han reportado diversas investigaciones en las que el objetivo central son la identificación de los factores claves de éxito de SS, tales como los reportes de Coronado and Antony (2002) en donde se hace énfasis en los proyectos, hasta los informes recientes de Laureani and Antony (2018) en los que se indica que el liderazgo es uno de los factores más importantes. De la misma manera, se han reportado diversos estudios en los que se han identificado los principales beneficios de SS, tales como Kwak and Anbari (2006) como pionero que además reporta los principales obstáculos, hasta los informes recientes de

Raman et al. (2017) donde se reporta el caso especial de empresas que se dedican a la exportación.

Asimismo, existen muchos estudios en los que se indica la necesidad de que las cadenas de suministro sean flexibles y ágiles para poder mejorar el desempeño de las mismas. Por ejemplo, Valeria Martínez, Jorge Luis García, José Roberto Díaz, and Deysi Guadalupe Marquez (2017) realizan un estudio para conocer el impacto que tienen las tecnologías de la información y la comunicación en la agilidad de la cadena de suministro, Braunscheidel and Suresh (2009) manifiestan que para lograr lo anterior, se requiere de una serie de cambios organizacionales de los que se deleguen responsabilidades para el cuidado de ese tipo de inversiones y también, Swafford, Ghosh, and Murthy (2006) ha generado un instrumento para evaluar los niveles de agilidad que tiene una empresa. De la misma manera, Gligor, Esmark, and Holcomb (2015a) realiza un estudio sobre los beneficios que pueden obtenerse de una cadena de suministro que es ágil y flexible.

Sin embargo, en la actualidad no existen suficientes estudios en los que se relacione a los FSE de SS con los beneficios obtenidos, ya que se han investigado esos dos aspectos de manera separada y ello es una oportunidad de investigación que debe explotarse, ya que esas relaciones podrán permitir identificar aquellas actividades que son más importantes para garantizar buenos resultados y de esta manera, los gerentes pueden focalizar su atención y recursos en esos FCE. De la misma manera, no existen suficientes trabajos de investigación en los que se asocie a la flexibilidad y agilidad de una cadena de suministro con los niveles de desempeño que estas tienen.

En la Figura 4.5 se representa de manera gráfica parte del problema de investigación, donde las variables independientes son la ejecución de las actividades o FCE de SS y las variables dependientes, son los beneficios obtenidos.

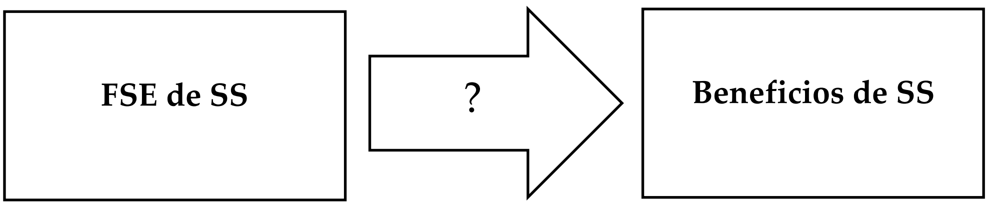

Figura 4.5 El problema de investigación (SS)

En la Figura 4.6 se ilustra un gráfico similar en el que se relaciona a la agilidad y flexibilidad de la cadena de suministro cono los beneficios que se pueden obtener. En este caso, la agilidad y flexibilidad son variables independientes y el desempeño de la cadena de suministro es la variable dependiente.

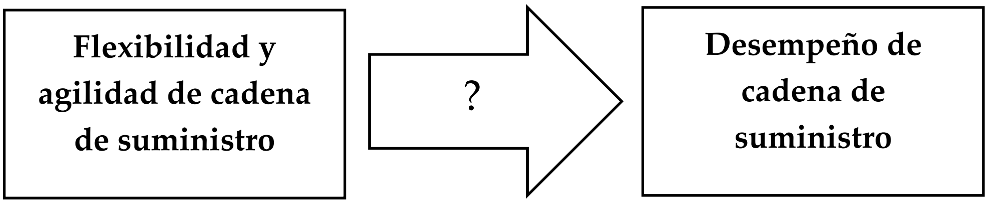

Figura 4.6 El problema de investigación (CS)

Objetivos de investigación

En esta sección se presenta el objetivo general y especifico que buscan dar solución a la problemática antes mencionada.

Objetivo general

Relacionar cuantitativamente los factores críticos de éxito de seis sigma con los beneficios que se obtienen en los sistemas productivos, así como determinar el efecto de la flexibilidad en la agilidad de la cadena de suministro y sus índices de desempeño.

Objetivos específicos

1. Cuantificar el impacto que tiene el conocimiento y comunicación en los beneficios operativos al implementar seis sigma en un sistema de producción.
2. Cuantificar la importancia de la estrategia de implementación de seis sigma en la inversión realizada por la en recursos humanos y los beneficios económicos obtenidos.
3. Determinar el impacto del factor humano en la flexibilidad y agilidad de la industria del vino de La Rioja.

Aportaciones del doctorando

Las aportaciones del doctorando en cada uno de los artículos publicados están relacionadas con el problema que se ha identificado en la introducción general que se ha descrito anteriormente, por lo que, con la finalidad de ser más específico en este aspecto, dichas aportaciones se realizan a continuación para cada uno de los mismos.

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

Es aceptado que seis sigma es una filosofía aplicada a los sistemas de producción, más que una simple técnica, ya que se asocia con el conocimiento de los recursos humanos que son responsables de implementarla y aunque existen muchos estudios que asocian ese nivel de conocimiento y la importancia de la capacitación con los beneficios obtenidos, son pocos los que las relacionan u obtienen una medida de dependencia. Es decir, el éxito de los programas de seis sigma se debe a factores humanos y el apoyo que se les brinde a éstos, tales como el acceso a la información, la capacitación en técnicas estadísticas y el materia didáctico usado, el fomento a la comunicación entre los grupos de mejora, entre otros, pero no se tienen estudios que cuantifiquen la relación que esas variables tienen.

La principal contribución de este artículo es que relaciona cuatro variables latentes concernientes con los procesos educativos, la información y comunicación que existe durante el proceso de implementación de seis sigma en un proceso de producción industrial y los beneficios operacionales que se obtienen. Se establecen diez hipótesis que relacionan a las variables y son evaluadas estadísticamente, donde como resultado se propone una medida de dependencia entre éstas, lo que indica la importancia de éstas y es interpretado como un nivel explicativo.

Otra contribución de este trabajo es el entorno en el que se realiza, ya que las variables se integran en un modelo de ecuaciones estructurales que es evaluado en el sector de la industria maquiladora de México, donde no existen trabajos similares. Los resultados permiten concluir que los recursos humanos y del nivel de conocimiento que deben tener éstos para lograr los beneficios ofrecidos por seis sigma, tales como la calidad y estandarización de los sistemas de producción.

Mediating Role of the Six Sigma Implementation Strategy and Investment in Human Resources in Economic Success and Sustainability

Este artículo es una continuación del anterior, en él se asume que no solamente se requiere de capacitación de los recursos humanos que implementan seis sigma, sino que se requiere de la voluntad y compromiso de los altos mandos gerenciales, ya que son éstos los que determinan la estrategia de implementación, así como los montos asignados a la capacitación y entrenamiento que se les debe proporcionar.

Por tal motivo, en este segundo artículo se presenta un modelo de ecuaciones estructurales que integra a cuatro variables latentes asociadas al compromiso gerencia, la estrategia de implementación de seis sigma, la inversión en recursos humanos y los beneficios económicos que se obtienen de seis sigma.

La principal contribución de este artículo es que va más allá de simplemente asociar a esas variables, sino que las relaciona mediante cinco hipótesis que son probadas estadísticamente con información empírica obtenida de la industria maquiladora de México. En el modelo se obtienen medidas de dependencia entre las variables, las cuales sirven para validar las hipótesis y, además, reporta la cantidad de varianza que pueden explicar las variables dependientes.

Los resultados permiten cuantificar el efecto que tiene una variable en otra y determinar el nivel de importancia que tiene para obtener los beneficios económicos que han reportado otras empresas y sectores industriales. Así, los gerentes podrán focalizar el uso de sus recursos para obtener los beneficios buscados.

Impact of human factor on flexibility and supply chain agility of La Rioja wineries

El estudio de la cadena de suministro es una área de oportunidad para las empresas, ya que de manera rápida se pueden obtener beneficios que se asocian con el desempeño de la empresa. En la actualidad existen muchos artículos que reportan estudios y casos analizados en la cadena de suministro, pero en su mayoría son asociados a industrias de manufactura y en menor medida a los productos agrícolas y perecederos, por lo que en este artículo se presenta un análisis de ésta, en la que se estudian los factores humanos, la flexibilidad del procesos de producción y la agilidad en la industria del vino establecida en La Rioja (España).

Nuevamente, se asume que los recursos humanos son el factor más importante que puede darle flexibilidad a los procesos de producción de las industria vitivinícolas, lo que trae como consecuencia una mayor agilidad de la cadena de suministro. Aquí se asume que la flexibilidad se refiere a las diferentes alternativas para generar un producto y la agilidad, se refiere a la velocidad con que se hace.

Las tres variables se integran en un modelo de ecuaciones que tiene solamente tres hipótesis que son validadas con información de 64 encuestas aplicadas en el sector vitivinícola de La Rioja, lo que representa la mayor contribución de este trabajo, ya que no existen estudios similares en ese sector en los que se integre a esas variables.

Los resultados permiten cuantificar la importancia de los recursos humanos en el logro de la flexibilidad de los procesos de producción y la agilidad de las cadena de suministro, lo que permite a los gerentes focalizar su atención en aspectos que le permitan tener una rápida respuesta a sus clientes.

Metodología

Para lograr el objetivo planteado de relacionar los FCE de SS con los beneficios de ésta y asociar la agilidad y flexibilidad de la CS con su desempeño, se sigue una metodología que ha sido dividida en etapas, tal como se ilustra a continuación.

Identificación de variables – Revisión de Literatura

El objeto de estudio es el proceso de implementación de SS en las empresas maquiladoras, los factores críticos de éxito (FCE) de la misma y los benéficos que se obtienen, así como la flexibilidad y agilidad de la CS y su desempeño, por lo que se realiza una revisión de literatura en bases de datos tales como Springer, Sciencedirect, Ingenta, Ebscohost, entre otras, con la finalidad de identificar las investigaciones que ya se han realizado al respecto.

Se colectaron los FCE e ítems que representan a la CS reportados en la literatura y se realizó una base de datos en la que se registraba el nombre del autor, la universidad y departamento de adscripción del mismo, el año de la publicación, nombre de la revista, sector industrial en casos de estudio, así como los factores y beneficios que se reportaban, lo que permite generar una distribución geográfica de los principales centros de investigación y sectores. Esta revisión de literatura constituye una validación racional del estado del arte del problema en cuestión (Yaşlıoğlu, Şap, & Toplu, 2014).

Afortunadamente, la identificación de esos FCE de SS han sido una preocupación de académicos y se han encontrado estudios muy específicos enfocados a determinarlos, tales como Brun (2011), Desai et al. (2012), Habidin and Yusof (2013), D. Tlapa et al. (2014), Fairul-Anwar and Mohd Amran (2015), Lande et al. (2016), Marzagão and Carvalho (2016a), Ribeiro de Jesus et al. (2016), Mustafa and Jamaluddin (2017) y Laureani and Antony (2018).

De la misma manera, los beneficios de SS son reportados en la literatura, aunque no con la misma intensidad que los FCE, se observa una clara tendencia a reportar aquellos de tipo financiero y económico. Algunos reportes de los beneficios de SS se pueden encontrar en Kwak and Anbari (2006), Antony et al. (2007), J. García-Alcaraz, Avelar-Sosa, Latorre-Biel, Jiménez-Macías, and Alor-Hernández (2017) y Raman et al. (2017).

De la misma manera, se han identificado trabajos en los que la flexibilidad de la cadena suministro es el objeto de estudio, enfocándose en varios aspectos (Fischer, Pfeiffer, Hellingrath, Scavarda, & Martins, 2014; Gosling et al., 2010; Jangga, Ali, Ismail, & Sahari, 2015; Manders et al., 2016; Moon, Yi, & Ngai, 2012; Sreedevi & Saranga, 2017), así como de la agilidad y sus beneficios (Gligor et al., 2015a, 2015b; Sangari et al., 2015; Yusuf et al., 2014).

Creación de un cuestionario

Con esos FCE de SS e ítems de agilidad y flexibilidad de la CS y beneficios obtenidos que han sido reportados en la literatura, se construyen dos cuestionarios iniciales. El primero es aplicado a la industria manufacturera de Ciudad Juárez con la finalidad de conocer los niveles de importancia que se le están dando a los mismos y determinar si se están obteniendo los beneficios reportados, mientras que el segundo se aplica al sector vitivinícola de La Rioja (España). El primer cuestionario contiene tres secciones principales, la primera se refiere a datos demográficos de la empresa en la cual se encuentra adscrito el encuestado, la segunda se refiere a los factores críticos de éxito para SS y finalmente, la tercera sección contiene los beneficios asociados con SS. Se identificaron un total de 60 FCE en la revisión de literatura, mismos que se integraron en 12 categorías a las que se llama variables latentes y también se identificaron un total de 19 beneficios que son integrados en tres categorías. En cambio, para el segundo cuestionario, asociado a la cadena de suministro, se usa una adaptación del instrumento usado por Avelar-Sosa et al. (2015) en el sector manufacturero y que es adaptado a la industria vitivinícola de España y dado que ya era un instrumento validado, no se hace referencia más a él.

Ese primer borrador del cuestionario de SS se entrega a gerentes de calidad y académicos para su revisión y adaptación al contexto regional, ya que los FCE han sido tomados de investigaciones realizadas en otros países en un sector diferente al de la industria maquiladora. Este proceso constituye una validación por jueces (J. Nunnally, 1978). Se agregan espacios en blanco para que los jueces propongan nuevos FCE de SS y beneficios, así como una sección de observaciones para que propongan nuevas redacciones a ítems que puedan ser confusos.

Los principales aspectos que los expertos deben evaluar son la consistencia, facilidad de entendimiento, relevancia, adaptación al contexto, entre otros (Prabhushankar, Devadasan, & Shalij, 2008).

El cuestionario usado para obtener información de seis sigma e las empresa manufactureras en México se encuentra en el Anexo 1, mientras que la encuesta de flexibilidad y agilidad de la cadena de suministro se encuentra en el Anexo 2. Aquí es importante mencionar que no todas las variables latentes se han analizado.

Encuesta piloto

Se realizan los ajustes al cuestionario en atención a las recomendaciones emitidas por los jueces y se construye una versión final de mismo, el cual es aplicado a 32 personas como una encuesta piloto y poder detectar errores antes de aplicarlo de manera masiva. Se analizan las respuestas no contestadas para investigar si existía dificultad de entendimiento y presentar una nueva redacción de la misma, ya que la adaptación de la encuesta es un paso importante para garantizar la calidad de la información obtenida (A. Zhang, Luo, Shi, Chia, & Sim, 2016). Se obtiene la mediana de las valoraciones emitidas por los encuestados con la finalidad de observar tendencias y se estima el rango intercuartílico (RI) como medida de dispersión, donde valores altos indican que no han consenso entre los encuestados que existen problemas en su entendimiento (Iacobucci, Posavac, Kardes, Schneider, & Popovich, 2015).

Con las adecuaciones de esa prueba piloto, se construye la versión final del cuestionario que será aplicado al sector de la industria maquiladora en Ciudad Juárez (México). Este tipo de pruebas rápidas han sido aplicadas en otros países para encontrar tendencias en la aplicación de SS (Douglas, Douglas, & Ochieng, 2015; A. Zhang et al., 2016).

Aplicación del cuestionario

Se identifican las empresas maquiladoras establecidas en Ciudad Juárez en el estado de Chihuahua en México y se establece contacto con ellas a través de los Departamentos de Calidad, contando con el apoyo de la IMMEX (Industria Maquiladora Mexicana de Exportación), una asociación civil que integra a ese sector.

Los principios de inclusión para responder el cuestionario es que los encuestados se encuentren adscritos a una empresa maquiladora que tenga servicios de exportación y con un programa de SS con más de cinco años de haber ido implementado que tengan el reconocimiento de directores de seis sigma, master black belt, black belt, green belt o yellow belt, que tengan al menos dos años de experiencia aplicando seis sigma o que hayan participado en al menos tres proyectos concluidos para garantizar que conozcan los resultados obtenidos y que pudieran contestar la sección de beneficios en el cuestionario. Esos principios de exclusión ayudan a focalizar la muestra y garantizar la calidad de la información (de Freitas et al., 2017).

El cuestionario debe responderse en escala Likert con valores entre uno y cinco. El uno indica que las actividades no son importantes en el proceso de implementación de SS o que los beneficios no se obtienen después de ello, mientras que el cinco indica que esas actividades eran cruciales para implementar la filosofía SS o que los beneficios siempre se obtenían. El dos, tres y cuatro se usan para valoraciones intermedias, tales como poco frecuente, regularmente y casi siempre. Esa escala ha sido empleada en estudios de SS por otro investigadores en otros contextos, tales como la estrategia de manufactura (Robb & Xie, 2003), el impacto se SS en el desempeño organizacional(de Freitas et al., 2017), para conocer el nivel de implementación de SS (de Jesus, Antony, Lepikson, & Teixeira Cavalcante, 2015), entre otros.

Todas las encuestas son aplicadas mediante entrevista personal con previa cita en horarios y fechas establecidas por el encuestado, quien es contactado a través de la IMMEX, lo que ayuda a evitar desviaciones en la interpretación de las pregunta (Ruppert et al., 2013). Durante el proceso de aplicación de la encuesta, debido a las múltiples ocupaciones de los posibles encuestados, frecuentemente se cancelaron las citas programadas. En el caso que se tenían más de tres cancelaciones a una cita, ese caso se abandona por requerir mucho tiempo y se enviaba coreo de agradecimiento.

Captura y depuración de la información

Se crea una base de datos para capturar la información en el software SPSS v.24, donde los renglones representan los casos o encuestas, mientras que las columnas representan a los FCE de SS y sus beneficios. A cada una de los FCE y beneficios se les asigna un acrónimo para facilitar su análisis.

Antes de cualquier análisis a la información, se realiza una depuración de la misma para evitar sesgos, enfocándose principalmente en los siguientes aspectos:

1. Se identifican los valores perdidos que aparecen en la base de datos, los cuales deben ser menores al 10% en cada uno de los casos. Aquellas encuestas que tenían un porcentaje mayor a esa cantidad fueron

eliminadas, pero en aquellos casos en que era menor, se procede a reemplazarlos por la mediana del ítem en cuestión, ya que se usa una escala ordinal y no se puede usar una media aritmética.

2. Para cada uno de los FCE y los beneficios de SS se identifican los valores extremos, debido a que pueden influir de manera negativa en la estimación de parámetros en los modelos y para ellos se realizan diagramas de caja. Los valores extremos son reemplazados por la mediana de cada uno de los ítems en cuestión.
3. Se obtiene la desviación estándar de cada uno de los casos o encuestas con la finalidad de identificar a los encuetados no comprometidos o que pudieran dar la misma respuesta a todos los FCE y beneficios. Valores menores a 0.5 en la desviación estándar de un caso en la escala Likert indican poco compromiso de los encuestados y ese caso es eliminado.

Validación de la información

Los 60 FCE se han integrado en 12 categorías o variables latentes, mientras que los beneficios se agrupan en solamente tres. A esas categorías se les llama variables latentes y a las FCE y beneficios valorados se les llama ítems. Las variables latentes antes de ser integradas en el modelo son validadas mediante los siguientes índices:

- Índice alfa de Cronbach y coeficiente de fiabilidad compuesta para medir la validez interna y se aceptan valores superiores a 0.7 (J. C. Nunnally, 1978). Se realizan análisis de sensibilidad en esta etapa, ya que frecuentemente al eliminar un ítem de la variable latente, la fiabilidad se incrementa.
- R-cuadrada y R-cuadrada ajustada para medir la validez predictiva de las variables latentes dependientes desde un punto de vista paramétrico y se aceptan valores mayores a 0.2 y Q-cuadrada para medir la validez predictiva desde un punto de vista no paramétrico y se aceptan valores similares a R-cuadrada y que sean mayores a cero (Hair, Black, Babin, & Anderson, 2009). La presencia de valores negativos indica que existen problemas en las relaciones entre variables.
- Promedio de varianza extraída (AVE) para medir la fiabilidad convergente y se aceptan valores superiores a 0.5 (Nitzl, 2016), lo que indica que se está explicando más del 70% de la variabilidad de la variable

latente.

- Índice de Inflación de la Varianza (VIF) para medir la colinealidad al interior de las variables latentes y entre sus ítems y se aceptan valores menores a 3.3 (N. Kock, 2011). Valores superiores indican que deben realizarse análisis iterativos para detectar ítems que tienen mucha relación o representan la misma pregunta con diferentes palabras.

Es importante mencionar que el proceso de validación de las variables latentes se obtiene de manera iterativa, ya que como se ha mencionado anteriormente, al eliminar algunos ítems, se logra incrementar el índice de Cronbach o eliminar problemas de colinealidad.

Análisis descriptivo de la muestra

Se realizan tablas cruzadas para identificar el género, número de empleados en las empresas, proyectos SS en los que han participado, el sector industrial al que pertenece la empresa, entre otros, lo que permite identificar tendencias en los sectores bajo estudio.

Análisis descriptivo de los ítems

Dado que los FCE de SS y beneficios obtenidos son evaluados en una escala Likert al obtener la información mediante el cuestionario, se obtiene la mediana como medida de tendencia central y el rango intercuartílico (RI) como medida de dispersión en lugar de la mediana y la desviación estándar, respectivamente. Valores altos en la mediana de un FCE de SS indican que éste es importante durante el proceso de implementación o que el beneficio siempre se obtiene como resultado de la misma, pero valores bajos indican en la mediana que ese FCE no se realiza o que los beneficios no se obtienen como consecuencia de la implementación de SS. En relación al RI, valores altos en los FCE o beneficios indican que no existe consenso en relación al verdadero valor medio de las actividades para SS y sus beneficios, pero valores bajos indican un alto consenso o acuerdo entre los encuestados. Lo anterior permite identificar las actividades para SS y beneficios más importantes en las categorías analizadas desde un punto de vista univariable.

Postulación de las hipótesis

Se crean doce categorías de FCE de SS y tres de beneficios, por lo que las hipótesis se generan en función de esas categorías o variables latentes y se refieren a las relaciones entre las mismas. Para proponer una relación entre variables latentes a través de una hipótesis, ante todo, se toma en cuenta la temporalidad de los eventos; por ejemplo, se asume que las actividades asociadas al control de los proyectos de seis sigma dependen de las actividades realizadas en la etapa de planeación, ya que ha ocurrido primero y por eso se puede plantear la hipótesis de que la planeación de SS tiene un efecto sobre el control de las mismas. De la misma manera, se usa el sentido común para relacionar las variables, tal como en el caso anterior, donde lógicamente las actividades realizadas en las primeras etapas de implementación de SS afectan a las actividades que deben realizarse después.

Asimismo, se realiza una justificación teórica de cada hipótesis o relación entre variables latentes mediante una revisión de literatura que permita inferir dicha relación, buscando integrar al menos tres referencias, las cuales deben ser preferentemente actualizadas y ser casos de estudio reportados en situaciones similares.

Modelo de ecuaciones estructurales - Validación de las hipótesis

Para la validación de las hipótesis o relaciones entre variables, se construyen modelos de ecuaciones estructurales (SEM), el cual es la integración de las hipótesis. Lógicamente, se busca relacionar los FCE de seis sigma con los beneficios; es decir, las variables latentes independientes son los FCE y los resultados son los beneficios.

El SEM se valida haciendo uso de la técnica de mínimos cuadrados parciales en el software WarpPLS v.6 y que es recomendado para la validación de teorías en las que se relacionan varias variables. Esa técnica se ha usado para conocer el impacto del conocimiento generado con SS en el desempeño organizacional (Boon Sin et al., 2015), para modelar el impacto de la técnica justo a tiempo (JIT) en el desempeño de la cadena de suministro (García, Rivera, Blanco, Jiménez, & Martínez, 2014), así como para determinar los factores críticos de éxito de SS en empresas manufactureras de Turquía (Kuvvetli, Firuzan, Alpaykut, & Gerger, 2016), entre otros. Además, los métodos basados en mínimos cuadrados parciales son recomendados para análisis de información obtenida en escala de tipo Likert (tal como en este caso), muestras pequeñas y datos no normales (Ned Kock, Verville, Danesh-Pajou, & DeLuca, 2009).

Antes de interpretar los resultados del modelo, se analizan sus índices de eficiencia para medir su ajuste a los datos analizados, lo cual se hace con un nivel de confianza del 95%. Los índices son recomendados por N. Kock (2014) y son los siguientes:

1. Promedio de los coeficientes de segmento (APC) para validar las relaciones entre las variables latentes y se busca p valores menores a 0.05.
2. Promedio de R-cuadrada (ARS) y promedio de R-cuadrada ajustada (AARS) para medir la validez predictiva del modelo y se buscan p valores menores a 0.05.
3. Promedio de bloque en índices de inflación de la varianza (AVIF) y promedio completo en índices de inflación de la varianza (AFVIF) para medir la colinealidad entre las variables latentes y se buscan valores menores a 3.3, aunque pueden aceptarse valores menores a 5.
4. Índice de Tenenhaus para medir el ajuste de los datos al modelo que se ha pnateado y valores mayores a 0.36 son aceptables.
5. Paradoja de Sympson (SPR) para analizar si un conjunto de variables tiene efecto contrario cuando se combinan y se buscan valores superiores a 0.7.
6. R-squared contribution ratio (RSCR)=1.000 para saber si las contribuciones de las variables latentes dependientes ayudan a explicar de manera significative a las variables latentes dependientes y se desean valores mayores a 0.7.
7. Índice de supresión estadística (SSR) el cual indica si el modelo y sus relaciones están libres de supresión estadística y se desean valores mayores a 0.7. Este índice es fácilmente detectado cuando se presentan valores de R cuadrados negativos.
8. Relación no lineal bivariada de causalidad de dirección (NLBCDR), que ayuda a determinar si la dirección de las hipótesis en las variables es la adecuada y se desean valores superiores a 0.7.

Una vez que el modelo es estadísticamente estable, se procede a interpretarlo y se consideran tres efectos en su análisis, todos ellos evaluados con un 95% de confianza. Para cada efecto se estima un valor de beta (β), el cual se expresa en desviaciones estándar y se estima un p-valor para determinar su significancia estadística. Siempre se prueba la hipótesis nula de que β=0 versus la hipótesis alternativa de que $\beta \neq 0$. Además, a cada efecto se le asocia un tamaño del efecto, el cual representa la porción de R-cuadrada que ayuda a explicar en la variable dependiente (Hayes & Preacher, 2010). Los efectos son:

- Efectos directos. Sirven para validar las hipótesis planteadas como relaciones entre las variables dependientes e independientes y existe uno por cada relación entre variables. Con cada efecto directo se reporta el valor de la beta como medida del mismo, el p valor asociado y el tamaño del efecto como medida de la variabilidad explicada.
- Efectos indirectos. Sirven para estimar los efectos que tiene una variable sobre otra, pero a través de una variable moderadora. Siempre son de dos o más segmentos y se representan por el producto de los efectos directos. Es posible que exista más de un efecto indirecto entre las variables y en esta investigación se reportan solamente la suma de los efectos indirectos. En cada efecto indirecto se indica la magnitud de este como valor de la beta, el p valor asociado y el tamaño del efecto.
- Efectos totales: Son la suma de los efectos directos e indirectos y se señalan los mismos índices que en los otros efectos.

Conclusiones finales

Se han evaluado tres modelos de ecuaciones estructurales, dos de ellos están relacionados con la implementación de SS en la industria maquiladora y uno evalúa la agilidad y flexibilidad de la cadena de suministro del vino. Las conclusiones que se realizan son en función de cada uno de los modelos, ya que éstos tenían objetivos diferentes.

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

En este modelo se han integrado un total de cinco variables latentes asociadas al éxito de seis sigma, tales como: Información, Materiales didácticos, Comunicación, Técnicas estadísticas y como respuesta se tiene a los Beneficios operacionales. Se han propuesto un total de 10 hipótesis que relacionan las variables y las conclusiones que se obtienen de ese trabajo son los siguientes:

Se analizaron un total de 301 encuestas y todos los ítems que componen las variables latentes tienen mediana superior a tres en promedio, por lo que se concluye que todas son más que regularmente realizadas. En el caso de la Información, se observa que existen reglas para la preservación y confidencialidad y que muchas veces, el acceso a la misma resulta difícil, lo que denota un área de oportunidad que debe ser superada, ya que puede ser causa del poco compromiso de los RH o abandono de los proyectos de SS iniciados, ya que se les motiva a mejorar el proceso de producción, pero a la vez se le restringe acceso a la información en etapas vitales y por ende, los proyectos pueden ser mal definidos.

En relación al uso de Técnicas estadísticas, se reporta el uso de gráficos y estadísticos, pero el uso de la metodología DMAIC ocupa el último puesto en esa categoría, y ello denota que el enfoque que se le da a SS es más como técnica estadística y no como metodología para resolver problemas, por lo que se debe buscar un balance para entre ambos conceptos para evitar que se convierta en un obstáculo (Kwak & Anbari, 2006) o una barrera para los participantes que no tengan suficiente fundamento de conceptos estadísticos.

También es importante observar que, en relación al Material didáctico, las instrucciones de los GB y BB son entendibles porque ocupan los primeros lugares, pero a veces, ese material es poco útil para otros proyectos, por lo que, si un equipo de trabaja en un proyecto, al culminarlo e iniciar otro, deberá pasar por otra etapa de entrenamiento, lo que representa un costo excesivo en ese concepto. En comunicación, se observa que los GB y BB dan soporte a los grupos de trabajo, pero se tiene un menor seguimiento de los avances que se tienen, es decir, se observa poca continuidad en los proyectos iniciados, lo cual puede ser desalentador para los integrantes del equipo de trabajo (Coronado & Antony, 2002).

Finalmente, con relación a los beneficios obtenidos, la calidad y reducción del tiempo de ciclo es lo que más se obtiene al implementar SS, pero se observa que el trabajo en equipo y trabajadores multifuncionales es lo que menos se obtiene. Aquí es importante mencionar que esos dos aspectos se relacionan con los RH de la empresa, por lo que debe hacerse un esfuerzo por agregar atributos humanos a SS, ya que los RH son quienes conocen los procedimientos, procesos productivos y las oportunidades de mejora (Harrison, 2006; Marzagão & Carvalho, 2016b).

Al analizar los efectos que existen entre las variables latentes analizadas, se puede concluir lo siguiente:

- En función de la Información disponible para el análisis de los problemas a resolver, los gerentes y la estructura organizacional para SS deben de definir las Técnicas estadísticas que deben enseñarse como herramientas de trabajo en los cursos de capacitación, pero también, deben diseñarse los cursos y Material didáctico que sea entendible y pueda ser usado en proyectos futuros.
- Aunque una empresa disponga de Información adecuada y accesible, esa variable no tiene un impacto sobre los Beneficio operativos de manera directa al implementar SS, ya que primero requiere completar el proceso educativo, donde se enseñen Técnicas estadísticas con Material didáctico adecuado, y además, debe facilitarse la Comunicación. Es decir, la Información y su calidad afecta a los Beneficios operativos de manera indirecta a través de otras variables mediadoras, lo que indica que, si está disponible pero no es adecuadamente analizada, no puede convertirse en algún tipo de beneficio, ya que se requiere un proceso de educación y Comunicación de la misma y de ahí la importancia que deben tener los gerentes en el proceso educativo.
- Se observa que el efecto directo entre la Información y las Técnicas estadísticas es el mal alto, lo que demuestra la importancia de dicha variable en la etapa inicial de la definición del problema que se busca resolver con SS, lo cual se demuestra al analizar los efectos totales que esa variable tiene sobre todas las demás, los cuales son los más altos y con

poder explicativo mayor. Pero si la Información no es accesible o confiable, entonces la definición de los problemas puede ser errónea.

- Otro de los efectos directos más altos que existen es la relación entre las variables Técnicas estadísticas y Material didáctico, lo que indica nuevamente que el proceso de enseñanza es de vital importancia al implementar SS.
- Es importante que los gerentes y estructura organizacional para SS hagan un esfuerzo por tener un proceso educativo adecuado en el proceso de implementación, con acceso a la Información y de utilidad, uso de Técnicas estadísticas básicas y Material didáctico entendible y de usos múltiples, ya que esas tres variables impactan de manera directa a la Comunicación, tanto vertical y horizontalmente. Si no existe un proceso educativo idóneo, el flujo de la Información falla al interior de la empresa y todas las variables involucradas disminuyen a su vez el efecto indirecto que se puede dar en los Beneficios operacionales obtenidos, usando a la Comunicación como variable mediadora.

Mediating Role of the Six Sigma Implementation Strategy and Investment in Human Resources in Economic Success and Sustainability

El éxito de seis sigma depende de varios factores y en este modelo se analizan cuatro de ellos: el Compromiso gerencial, la Estrategia de implementación, la inversión en recursos humanos y su impacto en los beneficios económicos. Se han planteado cinco hipótesis para relacionarlas y las conclusiones a que se puede llegar son las siguientes:

- SS sigue siendo aplicable hoy en día en los sistemas industriales, ya que es una herramienta usada para garantizar la calidad y ese concepto no ha pasado de moda, inclusive el tamaño de esa dimensión se ha incrementado con aspectos asociados a la globalización de los mercados y la personalización de los productos y servicios requeridos por el cliente.
- Para lograr los beneficios que ofrece SS se requiere del Compromiso gerencial, ya que son ellos los responsables de generar una Estrategia de implementación, y solamente de esta manera se garantizan procesos de producción flexibles, robustos y eficientes, tal como lo declara Andersson, Hilletofth, Manfredsson, and Hilmola (2014). Esa Estrategia de implementación no debe ser permanente, sino que la alta gerencia debe garantizar que sea dinámica y tener los ajustes necesarios de acuerdo a las necesidades cambiantes del cliente, ya que como menciona

Drohomeretski, Gouvea Da Costa, Pinheiro De Lima, and Garbuio (2014), debe estar basada en las operaciones y actividades diarias que demuestren ser capaces de resolver problemas, por lo que debe haber un proceso de retroalimentación entre las experiencias generadas al aplicar SS en las líneas de producción.

- Asumiendo que SS es una filosofía, entonces se requiere la integración de los recursos humanos para garantizar el éxito, tales como los programas de educación y entrenamiento para poder garantizar que los integrantes de los grupos de mejora pueden realizar análisis de la información obtenida y que son capaces de tomar decisiones en base a fundamentos estadísticos confiables y de hecho, Coleman (2008) considera que en las etapas iniciales de implementación es necesario contar con el apoyo de personal experto en estadística.
- Otra inversión en SS son las bonificaciones e incentivos que se debe ofrecer a los participantes de proyectos que obtengan resultados aceptables. No integrar un programa de recompensas puede ser la causa de múltiples abandonos y deserciones en los programas de SS, por lo que Arumugam, Antony, and Linderman (2016) recomienda estudiar su efecto e impacto, aunque Sabry (2014) indica que los incentivos son un CSF de menor importancia, se recomienda que se analicen los factores culturales.
- La Inversión en recursos humanos depende del Compromiso gerencial y de la adecuada Estrategia de implementación que se le dé a SS, donde se deben tener en cuenta las inversiones asociadas a capacitación, entrenamiento e incentivos.
- Los Beneficios económicos obtenidos de SS dependen de la Estrategia de implementación y de la Inversión en recursos humanos; sin embargo, la primera variable es la más importante.
- Una ruta crítica del modelo puede ser como sigue: Compromiso gerencial → Estrategia de implementación → Beneficios económicos, es decir, se requiere Compromiso gerencial para darle un buen enfoque a la Estrategia de implementación de proyectos SS y así poder garantizar los Beneficios económicos reportados en la literatura.
- El rol de la Inversiones en recursos humanos ha jugado un papel secundario en el impacto que se tiene sobre los Beneficios económicos obtenidos de SS, sin embargo, son parte esencial de la Estrategia de implementación, ya que son éstos quienes en realidad implementan los planes y programas que se crean en la alta gerencia, ya que como lo menciona Kavčič and Gošnik (2016), la educación y la transferencia de conocimientos que se genere de los distintos proyectos de SS es lo que hace

crecer a la empresa, misma que se deberá esforzar con conservarlo y transmitirlo.

Impact of human factor on flexibility and supply chain agility of La Rioja wineries

En este artículo se asume que los recursos humanos son la base del desempeño de las empresas vitivinícolas y que ello depende el nivel de flexibilidad y agilidad que se tenga. Se tienen tres hipótesis que relacionan esas variables y las conclusiones a las que se llega son las siguientes:

- Los recursos humanos son la plataforma principal para mejorar cualquier proceso de producción, incluidos los índices de desempeño de la SC y su gestión es crucial para el éxito de las empresas. Por lo tanto, es necesario invertir en nuevas capacidades y habilidades para los recursos humanos. Por ejemplo, la Universidad de La Rioja ofrece un título en Enología como respuesta a estas necesidades que tiene la región y debe mejorar constantemente ese programa en conjunto con las principales empresas vitivinícolas de la región y que dan empleo a sus egresados.
- Los recursos humanos son responsables del proceso de producción en una bodega de vinos, y sus habilidades y destrezas se reflejan en los índices de eficiencia del proceso. Así, bodegas de vino que cuenten con recursos humanos con altas capacidades y habilidades seguramente pueden resolver problemas que se presentan a lo largo de la cadena de suministro, lo que garantiza un flujo continuo de producción. De acuerdo al modelo, se observa que la flexibilidad de la cadena de suministro depende de los recursos humanos, y es por eso que es crucial para las universidades el poder garantizar la formación adecuada de sus egresados.
- Los recursos humanos son un factor de éxito de la agilidad en la agilidad de la cadena de suministro, ya que los hallazgos demuestran el efecto directo es muy bajo; sin embargo, el efecto indirecto resultó es muy alto y se da a través de la flexibilidad. Lo anterior demuestra que los recursos humanos son importantes para lograr la agilidad, pero primero deben ser capaces de ofrecer flexibilidad a la cadena de suministro.
- La agilidad de la cadena de suministro en empresas vitivinícolas es una consecuencia de los recursos humanos, aunque la relación entre variables es más alta con la flexibilidad, ya que ésta es más afectada por las habilidades y destrezas que tienen el personal y garantizan cambios rápidos en los procesos.

Final conclusions

Three structural equation model have been evaluated, in which two of them are related to six sigma implementations applied to the maquiladora industry while the other one only evaluates the agility and flexibility in wine´ supply chains. In addition, the conclusions reported in this section are based on each model, since they had different objectives.

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

In this model, five latent variables associated with six sigma success have been integrated, such as: Information, Didactic Materials, Communication, Statistical Techniques, as well as a response variable, which is the Operational Benefits. Also, ten hypotheses are relating the variables and conclusions that are obtained from the present research, which are the following:

As a matter of fact, 301 surveys were analyzed, and all the items that were integrated into the latent variables have a median over three, on average, therefore, it is concluded that all of them are more than regularly performed. In addition, in the Information variable, it is observed that there are rules for its preservation and confidentiality and that often, access to it is difficult, which denotes an opportunity area that must be overcome, since it can be a source of a lack of commitment from human resources or six sigma initiated projects abandonment, since they are motivated to improve the production process, but at the same time they have restricted access to information in significant implementation stages, consequently, the projects can be not well-defined.

Regarding Statistical techniques implementation, graphs, and statistic parameters are reported, but the DMAIC methodology implementation has the last position in that section, because is not regularly used, which shows that the SS approach is implemented as a statistical technique and not as a methodology to solve problems, as a result, that is why managers should look for a balance between both concepts in order to avoid that it becomes an obstacle (Kwak & Anbari, 2006) or a barrier for participants who do not have enough deep acknowledge in statistical concepts.

Furthermore, it is relevant to mention that, regarding the didactic material, the GB and BB instructions are understandable for operators, because those items are in the first places from the implementation, but sometimes, that material is not very useful for other training projects, therefore, if a team works in one project and finish it and after they start another one, they must go through another training stage, which represents an excessive cost in that concept. Also, in communication, it is observed that the GB and BB give support to the working groups, but there is less monitoring about the progress that has been made, in other words, there is a little continuity on initiated projects, which can be discourage for the members in a teamwork (Coronado & Antony, 2002).

Finally, the most obtained benefits by implementing SS are quality products and cycle time reduction, however, it is observed that teamwork and multifunctional workers are the least obtained. In addition, it is crucial to mention that those two aspects are related to the human resources in the company, therefore, an effort must be made to add human attributes to SS, because they are the ones who know procedures, production processes, and opportunities to perform improvement resources (Harrison, 2006; Marzagão & Carvalho, 2016b).

When analyzing the effects between the latent variables in the model, the following can be concluded:

- Based on Information available in order that the problem analysis is solved, managers and the organizational structure for SS must define the statistical techniques that should be taught as work tools in training courses, but also, the courses and Didactic material must be understandable and aimed to be used in future projects.
- Even though, a company may have adequate and accessible information, that variable does not have an impact on operating benefits directly when implementing SS, since, first it is necessary to complete the educational process, where Statistical techniques with appropriate teaching materials are taught, as well as the Communication is facilitated. In other words, the Information and its quality may affect the operating benefits indirectly through other mediating variables, which indicates that, if it is available but not properly analyzed, it cannot be any type of benefit, since education and communication process is required in this process, as a consequence, it is crucial that managers must consider the educational process relevant.
- It was observed that the direct effect between the Information and Statistical techniques is the highest, which shows the importance of this variable in the initial stage of the problem definition to be solved with SS, which can be seen when analyzing the total effects that this variable has over all others, which are the highest as well as with the greatest explanatory power. However, if the Information is not accessible or

reliable, as a result, the problem definition may be wrong.

- Another of the highest direct effects is the relationship between Statistical techniques and Didactic materials variables, which again indicates that the teaching process is vital when implementing SS.
- It is important that managers and all organizational structure for SS try to have an adequate educational process in its implementation, along with access to Information and usefulness, basic Statistical techniques, and multi-use teaching material usage, since these three variables directly impact the Communication, both vertically and horizontally. In addition, if there is no suitable educational process, the information flow may fail within the company, and all the variables involved may decrease the indirect effect that may be given to the Operational benefits obtained, while Communication as a mediating variable is implemented.

Mediating Role of the Six Sigma Implementation Strategy and Investment in Human Resources in Economic Success and Sustainability

The six-sigma success depends on several factors, and in this model four of them are analyzed: the Management commitment, the Implementation strategy, the Investment in human resources and its impact on Economic benefits. In addition, five hypotheses or relationships have been proposed, and the conclusions that can be reached are as follow:

- SS is still implemented today in the industrial systems, as it is a tool used to guarantee quality and that concept is still present on companies, even the size of that dimension has increased with aspects associated with the markets globalization, products customization, and services required by clients.
- In order to achieve the benefits offered by SS, the Management commitment is required, since managers are responsible for generating an Implementation strategy, and only in this way the flexible, efficient, and high production processes can be guaranteed, as stated by Andersson, Hilletofth, Manfredsson, and Hilmola (2014). Moreover, this Implementation strategy should not be permanent, however, senior management should ensure that it is dynamic and have the necessary adjustments according to changing needs from clients, as mentioned by Drohomeretski, Gouvea Da Costa, Pinheiro De Lima, and Garbuio (2014). In addition, that Implementation strategy must be based on daily operations and activities that demonstrate that it is able to solve problems,

therefore, there must be a feedback process with the experiences generated when applying SS in the production lines.

- Assuming that SS is a philosophy, then it requires the integration of human resources to ensure success, such as education and training programs to ensure that the members in the improvement groups may perform a proper analysis about the data obtained, and that they are able to make decisions based on reliable statistical foundations, in fact, Coleman (2008) considers that in the initial stages of SS implementation it is necessary to have the professional support from an expert staff in statistics.
- Another investment in SS are the bonuses and incentives that must be offered to participants in projects that obtain acceptable results. In other words, by not integrating a rewarding program may be the cause of multiple dropouts in SS programs, that's why Arumugam, Antony, and Linderman (2016) recommends studying its effect and impact in benefits, although Sabry (2014) indicates that the incentives are a minor CSF, because it is recommended to analyze cultural factors regarding human factors.
- Investment in human resources depends from Management commitment and the Implementation strategy that is given to SS, where the investments associated with training and incentives must be taken into account.
- The Economic benefits obtained from SS depend on the Implementation strategy and the Investment in human resources; however, the first variable is the most relevant.
- A critical path of the model can be as follows: Management commitment → Implementation strategy →Economic benefits, that is, Management commitment is required to give a good approach to the SS project Implementation strategy and thus be able to guarantee the Economic benefits reported in the literature.
- The Investments in human resources has played a secondary role in the impact that has on the Economic benefits obtained from SS, however, they are an essential part of the Implementation strategy, since they are who actually implement plans and programs that are created by senior managers, since as Kavčič and Gošnik (2016) mention, education and knowledge transfer that is generated from different SS projects is what makes the company grow better, consequently, it should be encourage to be preserved and transmitted.

Impact of human factor on flexibility and supply chain agility of La Rioja wineries

In the present paper, it is assumed that human resources are the basis for the performance in wine companies, and that this depends on the level of flexibility and agility in the supply chain. Also, the model that is reported has three hypotheses that relate these variables and the conclusions, which are the following:

- Human resources are the main resources to improve any production process, including the performance indexes in a CS, and its management is crucial for the success in companies. Therefore, it is necessary to invest in new skills and abilities for human resources. For instance, the University of La Rioja offers a degree in Enology in response to those regional needs, and it must constantly improve this program along with the main wine companies that employ their graduated students in La Rioja region.
- Human resources are responsible for the production process in wine companies, and their skills and abilities are reflected in the efficiency indexes that are obtained in the process. Thus, wineries that have human resources with high capacities and skills may surely solve problems that occur along the supply chain, which guarantees a continuous flow in the production process. According to the proposed model, it is observed that production process flexibility depends on human resources, and that is why it is crucial for universities to be able to guarantee the adequate training to their graduates.
- Human resources are a critical success factor for supply chain, however the findings in this research show that the direct effect is very low; however, the indirect effect is high and is given through flexibility. In addition, the previous findings demonstrate that Human resources are essential to achieve Supply chain agility, but first they must be able to offer Flexibility in their production process.
- Supply chain agility in wineries is a consequence from Human resources, although the relationship between variables is higher with Flexibility, since this is more affected by the personnel skills and abilities, which guarantee quick changes in the production processes.

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SECCION V. APÉNDICE

En este apéndice se indican ciertas informaciones relativas a los trabajos incluidos en la memoria de esta tesis como compendio de publicaciones y también acerca de las revistas científicas en las que se han realizado dichas publicaciones.

Las referencias a las publicaciones que constan en el presente anexo se han realizado de la siguiente forma:

Publicación 1: García-Alcaraz, J.L., Avelar-Sosa, L., Latorre-Biel, J.I., Jiménez-Macías, E., Alor-Hernández, G. Role of Human Knowledge and Communication on Operational Benefits Gained from Six Sigma. Sustainability 2017, 9(10), 1721. September 2017. https://doi.org/10.3390/su9101721

Publicación 2: García-Alcaraz, J.L., Alor-Hernández, G., Sánchez-Ramírez, C., Jiménez-Macías, E., Blanco-Fernández, J. and Latorre-Biel, J.I. Mediating Role of the Six Sigma Implementation Strategy and Investment in Human Resources in Economic Success and Sustainability. Sustainability 2018, 10(6), 1828. June 2018. https://doi.org/10.3390/su10061828

Publicación 3: García-Alcaraz, J.L., Maldonado-Macías, A.A., Alor-Hernández, G., Jiménez-Macías, E., Sáenz Díez Muro, J.C., and Blanco-Fernández, J. Impact of human factor on flexibility and supply chain agility of La Rioja wineries. European J. Industrial Engineering, Vol. 11, No. 5, 2017. https://doi.org/10.1504/EJIE.2017.087703

A continuación, se indica el factor de impacto de las revistas científicas internacionales con revisión por pares en las que se han realizado las publicaciones que se han reunido en esta memoria por compendio. El factor de impacto es el que corresponde a la edición 2018 de Journal Citation Reports.

Las publicaciones 1 y 2 han aparecido en la revista científica internacional "Sustainability". Algunos de sus parámetros bibliométricos más destacados se indican a continuación.

Sustainability
ISSN: 2071-1050
MDPI AG
ST ALBAN-ANLAGE 66,CH-4052 BASEL,SWITZERLAND
SWITZERLAND

Go to Journal Table of Contents   Go to Ulrich's

Titles
ISO: Sustainability
JCR Abbrev: SUSTAINABILITY-BASEL

Categories
GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY - SCIE;
ENVIRONMENTAL SCIENCES - SCIE;

Languages
English

12 Issues/Year;
Open Access from 2009

Key Indicators

Year	Total Cites Graph	Journal Impact Factor Graph	Impact Factor Without Journal Self Cites Graph	5 Year Impact Factor Graph	Immediacy Index Graph	Citable Items Graph	Cited Half-Life Graph	Citing Half-Life Graph	Eigenfactor Score Graph	Article Influence Score Graph	% Articles in Citable Items Graph	Normalized Eigenfactor Graph	Average JIF Percentile Graph
2017	8,904	2.075	1.364	2.177	0.483	2,346	2.4	7.2	0.01...	0.322	94.50	1.60...	49.967
2016	4,488	1.789	1.161	1.850	0.394	1,331	2.3	7.4	0.00...	0.333	94.74	1.04...	47.296
2015	2,301	1.343	0.859	Not ...	0.361	832	2.5	7.6	0.00...	Not ...	96.03	0.751...	31.765
2014	1,163	0.942	0.644	Not ...	0.260	497	3.1	7.7	0.00...	Not ...	95.17	0.48...	23.400
2013	681	1.077	0.860	Not ...	0.204	279	2.9	7.4	0.00...	Not ...	92.83	0.32...	33.600

Figura 5.1 Factor de impacto de la revista Sustainability

Fuente: Journal Citation Reports 2017

Es conveniente mencionar que esa revista se encuentra indexada en dos ctegorias, en una de ellas es Q3 y en otra es Q2, tal como se ilustra a continuacion:

JCR Impact Factor

JCR Year	GREEN & SUSTAINABLE SCIENCE & TECHNOLOG			ENVIRONMENTAL SCIENCES		
	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile
2017	21/33	Q3	37.879	120/241	Q2	50.415
2016	18/31	Q3	43.548	119/229	Q3	48.253
2015	22/29	Q4	25.862	146/225	Q3	35.333
2014	NA	undefined		176/223	Q4	21.300
2013	NA	undefined		154/216	Q3	28.935

Figura 5.2 Ranking de la revista Sustainability

Fuente: Journal Citation Reports 2017

La publicación 3 ha aparecido en la revista "European Journal of Industrial Engineering". Algunos de sus parámetros bibliométricos más destacados se indican a continuación.

European Journal of Industrial Engineering

ISSN: 1751-5254

INDERSCIENCE ENTERPRISES LTD
WORLD TRADE CENTER BLDG, 29 ROUTE DE PRE-BOIS, CASE POSTALE 856,CH-1215 GENEVA,SWITZERLAND
ENGLAND

Go to Journal Table of Contents   Go to Ulrich's

Titles
ISO: Eur. J. Ind. Eng.
JCR Abbrev: EUR J IND ENG

Categories
ENGINEERING, INDUSTRIAL - SCIE;
OPERATIONS RESEARCH & MANAGEMENT SCIENCE - SCIE;

Languages
English

4 Issues/Year;

Key Indicators

Year	Total Cites Graph	Journal Impact Factor Graph	Impact Factor Without Journal Self Cites Graph	5 Year Impact Factor Graph	Immediacy Index Graph	Citable Items Graph	Cited Half-Life Graph	Citing Half-Life Graph	Eigenfacto Score Graph	Article Influence Score Graph	% Articles in Citable Items Graph	Normalizec Eigenfacto Graph	Average JIF Percentile Graph
2017	296	1.085	0.802	1.056	0.147	34	4.8	7.7	0.00...	0.229	100.00	0.06...	25.788
2016	237	0.775	0.605	0.970	0.133	30	4.7	>10.0	0.00...	0.230	96.67	0.06...	19.599
2015	230	0.718	0.464	1.091	0.100	30	3.9	8.4	0.00...	0.281	100.00	0.07...	20.164
2014	166	0.736	0.541	0.866	0.103	29	3.9	9.7	0.00...	0.221	100.00	0.05...	25.955
2013	225	1.500	1.316	1.554	0.056	36	3.4	9.3	0.00...	0.403	100.00	0.09...	70.062
2012	165	1.596	1.148	1.390	0.028	36	3.2	9.8	0.00...	0.424	97.22	Not ...	75.223
2011	42	0.413	0.369	0.415	0.125	24	Not A...	9.8	0.00...	0.161	100.00	Not ...	17.865
2010	102	1.787	1.787	1.366	0.217	23	2.0	>10.0	0.00...	0.488	95.65	Not ...	82.412
2009	53	1.104	1.062	1.104	0	23	Not A...	8.9	0.00...	0.552	95.65	Not ...	57.497

Figura 5.3 Factor de impacto de la revista European Journal of Industrial Engineering

Fuente: Journal Citation Reports 2017

La revista es considerada Q3 y Q4, según la categoría en la que se analice, tal como se indica a continuación:

JCR Impact Factor

JCR Year	ENGINEERING, INDUSTRIAL			OPERATIONS RESEARCH & MANAGEMENT SCIEN		
	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile
2017	36/47	Q4	24.468	61/83	Q3	27.108
2016	36/44	Q4	19.318	67/83	Q4	19.880
2015	34/44	Q4	23.864	69/82	Q4	16.463
2014	31/43	Q3	29.070	63/81	Q4	22.840
2013	14/43	Q2	68.605	23/79	Q2	71.519
2012	12/44	Q2	73.864	19/79	Q1	76.582
2011	34/43	Q4	22.093	67/77	Q4	13.636
2010	5/38	Q1	88.158	18/75	Q1	76.667
2009	17/37	Q2	55.405	30/73	Q2	59.589

Figura 5.4 Ranking de la revista European Journal of Industrial Engineering

Fuente: Journal Citation Reports 2017

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Las áreas temáticas de las publicaciones, de acuerdo a los códigos UNESCO (nomenclatura internacional de la UNESCO para los campos de ciencia y tecnología), son las siguientes:

331003 Procesos Industriales

331005 Ingeniería de Procesos

331006 Especificaciones de Procesos

531107 Investigación Operativa

531108 Niveles Óptimos de Producción

531109 Organización de la Producción (Ver 3310.07)

531208 Fabricación

Por otra parte, las publicaciones comentadas en este anexo han sido realizadas en coautoría. Por ese motivo, a continuación, se justifica la contribución del doctorando en cada una de ellas:

Publicación 1: Jorge Luis García Alcaraz ha sido el responsable de realizar el diseño de la investigación, líder en la aplicación de encuestas con el sector industrial, ha dirigido el análisis de la información e interpretación de ésta. Como autor corresponsal, ha establecido contacto con la editorial hasta la publicación del artículo.

Publicación 2: Jorge Luis García Alcaraz realizó el diseño del instrumento de valoración que fue aplicado en las empresas, estableció contacto con las mismas para aplicar las encuestas, realizó el análisis e interpretación de la información. Asimismo, dirigió la escritura y fue autor corresponsal ante la editorial.

Publicación 3: Jorge Luis García Alcaraz fue el responsable de adaptar el cuestionario aplicado al sector del vino de la Rioja. Apoyo en la obtención de la información junto a Emilio Jiménez Macías, realizó el análisis de la información, generó el modelo de ecuaciones estructurales, dirigió la interpretación del mismo y estableció contacto con la editorial, siendo el autor de correspondencia.