

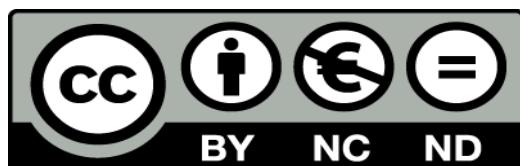


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TESIS DOCTORAL

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**UNIVERSIDAD
DE LA RIOJA**

Escuela Técnica Superior de Ingeniería Industrial

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Innovación en Ingeniería de Producto y Proceso Industriales

(Plan 881D)

Tesis Doctoral:

**PROVEEDORES Y PROCESOS PRODUCTIVOS
VERDES Y LOS BENEFICIOS OBTENIDOS EN
LA INDUSTRIA MANUFACTURERA.**

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DEDICATORIA

Todavía no soy ni la mitad de la persona que deseo ser. Aún tengo que trabajar mucho en mi pero gracias a mi madre Isabel Fong Yañez, voy por el buen camino.

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No hay que apagar la luz del otro para lograr
que brille la nuestra.

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RESUMEN

La conciencia medio ambiental en estos momentos es exigida cada vez más y no solo para los países de primer mundo o con un desarrollo industrializado muy avanzado. Ya que el desarrollo ambiental corporativo, se está convirtiendo como una estratégica del negocio y es uno de los cambios más significativos que comenzaron a ocurrir en los mercados actuales. Esas acciones en el área ambiental se volvieron proactivas y comenzaron a entenderse como innovaciones obligatorias y no solo como una estrategia competitiva en la manufactura industrial.

Se pueden utilizar varias prácticas medioambientales, como el análisis del ciclo de vida de un producto y el diseño de productos con un enfoque ecológico, la selección de proveedores verdes, la distribución sustentable y tópicos que han sido una tendencia mundial creciente en la manufactura industrial.

Mas sin embargo la herramienta más utilizada en la manufactura industrial mundial es la implementación de una Cadena de Suministros Verde (CSV), ya que dicha cadena tiene la clave para desarrollar nuevos productos, sistemas y servicios con prácticas medioambientales y que al mismo tiempo que reduce el uso de recursos, minimiza el impacto ambiental.

Pero a pesar de lo anterior para países terciermundistas y con un grado de desarrollo industrial más bajo, implementar un CSV exitosa, se vuelve una tarea bastante complicada, ya que no se cuenta con la cultura, la responsabilidad social, el apoyo gubernamental y un presupuesto económico limitado; además de que se piensa que tener un pensamiento verde en sus organizaciones conlleva costos económicos elevados y no rentables.

Por lo anterior en este documento de tesis se presentan tres investigaciones enfocadas en la manufactura industrial mexicana donde se demuestra cualitativamente que implementar un CSV exitosa es posible y que además de eso se garantizará con dicha implementación una serie de beneficios que impactaran de manera positiva a la economía, los procesos y la comercialización de las organizaciones.

Se hace uso de la metodología basada en dos modelos de ecuaciones estructurales para demostrar la relación positiva que conlleva seleccionar un Proveedor Verde (PV) con el uso de atributos y el de transformar un proceso de manufactura tradicional a un proceso de Manufactura Verde (MV); en la implementación exitosa de un CSV y la generación de una serie de beneficios.

Finalmente se presenta un modelo de ecuaciones estructurales donde se relacionan a las Tecnologías de Información y Comunicación (TIC) como una herramienta para ayudar en la implementación exitosa de una CSV, ya que estas herramientas facilitan la comunicación, se optimizarán los procesos productivos y de distribución en la manufactura industrial.

ABSTRACT

Right now, the environmental awareness is demanded more and more and not only for first world countries or countries with a very advanced industrialized development. The environmental corporate development is becoming a business strategy and it is one of the most significant changes in today's markets. Those actions in the environmental area became proactive and began to be understood as mandatory innovations and not only as a competitive strategy in industrial manufacturing.

Several environmental practices can be used, such as products' life cycle analysis and designs with an ecological approach, the selection of green suppliers, the sustainable distribution and topics that have been a growing global trend in the industrial manufacturing.

However, the most used tool in the global industrial manufacturing is the implementation of a Green Supply Chain (GSC), since this chain has the key to develop new products, systems and services with environmental practices and reduces the use of resources while minimizing the environmental impact.

Despite the above, carry out a successful GSC for third world countries with a lower degree of industrial development, it becomes a fairly difficult task, since there is no culture, social responsibility, or government support, and there is a limited economical budget. In addition, it is surmised that having green thinking in your organization entails high and unprofitable economic costs.

Therefore, this thesis document presents three studies focused on Mexican industrial manufacturing where it is demonstrated qualitatively that implementing a successful GSC is possible and besides that, a series of benefits will be guaranteed and will have a positive impact on the economy, processes and marketing of organizations.

A methodology based on two structural equations models is used to demonstrate the positive relationship which entails selecting a Green Supplier (GS) with the use of attributes and transforming the traditional manufacturing process into a Green Manufacturing (GM) process; in the successful implementation of a GSC and the generation of a series of benefits.

Finally, a structural equations model is presented relating Information and Communication Technologies (ICT), as a tool to help in the successful implementation of a GSC, since these tools facilitate communication, the production and distribution processes will be optimized in manufacturing industry.

1. INTRODUCCIÓN

A continuación se presentarán una preámbulo de los conceptos relacionados con el tópico principal de esta investigación que es la CSV. Por lo que se empieza por definir lo que es una Cadena de Suministros (CS) típica, así como la definición de una CSV y se presenta la importancia que tiene contar en estos momentos con una CSV.

La CSV es una filosofía para mejorar el producto, los proceso y la distribución de bienes o servicios; con el objetivo de integrar y garantizar los aspectos ambientales, sociales y económicos en una determinada organización. Igualmente se busca que la CSV elimine el consumo ineficiente de recursos, reduzca las emisiones nocivas para el medio ambiente, etcétera.

Sin embargo tener una CSV no es algo muy sencillo de lograr y más para países en desarrollo. Por anterior, se presenta conceptos como los PV, MV y las TIC, factores para implementar un CSV de manera sencilla y exitosamente. Y para incentivar más la implementación de una CSV también se presentas los beneficios que se obtiene con tener una CSV implementada con los factores aquí mencionados.

1.1 CADENA DE SUMINISTROS VERDE

Una CS típica puede ser definida como una red compuesta por todas las partes involucradas (por ejemplo, proveedor, fabricante, distribuidor, mayorista, minorista, cliente, etc.), directa o indirectamente, en la producción y entrega de productos o servicios a los clientes finales, tanto en sentido ascendente como descendente. A través de la distribución física, el flujo de información y las finanzas (Chin, Tat, & Sulaiman, 2015).

Sin embargo hoy en día las actividades de CS están siendo cada vez más relacionadas al calentamiento global, el agotamiento de los recursos naturales y a la contaminación en general (Jadhav, Orr, & Malik, 2018); lo cual ha logrado que las empresas responsables de una CS y la sociedad tomen parte en la responsabilidad de minimizar los impactos ambientales que genera una CS (Laari, Töyli, & Ojala, 2017); lo cual ha hecho que surja la CSV como una forma de combinar la gestión ambiental y la gestión de la cadena de suministro típica.

Una CSV busca la colaboración estratégica con socios clave como los proveedores, productores, distribuidores, clientes y usuarios finales (Al-Sheyadi, Muylldermans, & Kauppi, 2019) ya que se busca una gestión eficaz y eficiente de las actividades relacionadas con el flujo de productos, servicios, información y finanzas (Jajja, Chatha, & Farooq, 2018); pero integrando un pensamiento verde, tanto en el diseño ecológico de procesos y productos, abastecimiento y distribución sustentable, reciclaje, remanufactura, entre muchas otras actividades.

Las implicaciones ambientales y sociales han sido percibidas cada vez más como partes integrales del desempeño de la CSV por parte de los interesados, por lo que la CSV se ha convertido en una herramienta importante en las industrias para lograr los objetivos de ganancias económicas y participación verde en el mercado al reducir sus riesgos ambientales y al aumentar su eficiencia ecológica (R. K. Singh, Rastogi, & Aggarwal, 2016).

Por lo anterior se puede definir a la CSV como la integración del pensamiento ambiental en la gestión de la CS tradicional, incluyendo el diseño del producto, la selección del proveedor y el suministro de materiales, los procesos de fabricación, el embalaje del producto, la entrega del producto a los consumidores y la gestión del final de la vida útil del producto después de su uso (Younis, Sundarakani, & Vel, 2016).

La ecologización de la CSV ofrece un desafío y la oportunidad de competir también por métodos de producción sostenibles y un amplio conocimiento sobre la fabricación verde y los productos ecológicos. Y es crucial y requiere coordinación desde todos los niveles de la fuerza laboral, desde los empleados de la línea de base hasta la alta gerencia para lograrla (Thakker & Rane, 2018).

En conclusión en estos tiempos no contar con una CSV es estar perdiendo una serie de beneficios tangibles, como la reducción de costos, la mejora de la calidad, la reducción de desechos, la reducción de los plazos de entrega, rentabilidad positiva de las existencias y conservación de la energía. Y beneficios intangibles como: mayor competitividad, mayor valor para los accionistas, mayor satisfacción del cliente, mayor satisfacción en el trabajo, mayor eficiencia y nuevas oportunidades de mercado (Younis et al., 2016).

1.2 FACTORES PARA IMPLANTAR UNA CADENA DE SUMINISTROS VERDES

La CSV es un mecanismo potencialmente y eficaz para mejorar el historial de la empresa en responsabilidad social corporativa, disminuir los riesgos para la reputación, reducir los desechos y aumentar la flexibilidad para responder a las nuevas regulaciones ambientales. Igualmente la CSV se está convirtiendo en una herramienta importante para muchas industrias para lograr los objetivos de ganancias y participación de mercado al reducir sus riesgos ambientales y al aumentar su eficiencia ecológica.

Todas CSV deben seguir y mantener estándares estrictos en cuanto a que todas sus etapas, procesos y componentes importantes para lograr una imagen verde en la organización, producto, percepciones de los empleados, proveedores y clientes; y al mismo tiempo reducir el consumo de recursos, la contaminación y también cumplir con los estándares ambientales definidos (R. K. Singh et al., 2016).

Se han considerado la implementación de una CSV como una práctica de gestión ecológica exitosa. Ya que la CSV puede integrar un pensamiento verde en todos los ámbitos de la organización (Dubey, Gunasekaran, Papadopoulos, & Childe, 2015). Las medidas

ecológicas deberán desarrollarse a través de un marco integral de una CSV para fomentar el pensamiento medioambiental y ecológico a lo largo de la misma (Sahu, Sahu, & Sahu, 2018).

En definitiva el proceso de implementación de una CSV es complejo y largo por lo cual se recomienda que las organizaciones, busque la participación activa de todos los involucrados y participes a lo largo de una CS y además de utilizar las herramientas novedosas y al alcance de la organización para facilitar y optimizar el proceso de implementación y lograrlo de manera exitosa.

No obstante, cada vez existen más herramientas, colaboraciones estratégicas, prácticas y alineamientos competitivos para ir adoptando paulatinamente el pensamiento verde en una organización, y así lograr la transformación de una CS tradicional a una CSV de forma exitosa. Así pues, la CSV no deberá ser un imperativo estratégico para la organización sino deberá de ir involucrando poco a poco a los principales responsables y participes de la misma para ir contagiando y sosteniendo el pensamiento verde a lo largo de la CSV.

1.2.1 SELECCIÓN DE PROVEEDORES VERDES

En el entorno competitivo actual y global la mayoría de las empresas, buscan no fallar en uno de los procesos más importantes en la gestión de su CSV; que es la selección de sus PV. Este proceso juega un papel importante en la determinación del costo, la calidad, el desempeño y la satisfacción del cliente final (Hamdan & Cheaitou, 2017a).

Ya que los PV serán el inicio y uno de los integrantes más significativos para lograr el buen funcionamiento de un CSV, ya que de ellos dependerá en gran parte el éxito, el desempeño y gestión de esta. Por lo anterior cientos de estudios han discutido la importancia en la correcta selección de PV en términos de mejorar y facilitar el desempeño ambiental a lo largo de la CSV (Jia, Govindan, Choi, & Rajendran, 2015).

Un PV será el encargado de abastecer de materia prima, componentes, subensambles, en el tiempo pedido, en la cantidad y con la calidad necesaria, además de lograr estas actividades con el mínimo impacto medioambiental a lo largo de la CSV. Sin embargo, la evaluación y selección de un PV es una de las tareas en las que organizaciones encuentra problemas ya que encontrar al PV correcto no es fácil.

El proceso de selección de un PV contiene un conjunto de actividades, tales como la identificación, análisis, evaluación y selección (Banaeian, Mobli, Fahimnia, Nielsen, & Omid, 2018). Sin embargo, la amplitud y diversidad de proveedores, así como la implicación de muchos factores incontrolables e impredecibles hace que el proceso de selección se vuelva complicado.

Algunos autores reportan que para la selección y evaluación de un PV se deben tener en cuenta dos aspectos: por una parte, qué atributos deben utilizarse y por otra parte, qué método debe aplicarse (Govindan, Shankar, & Kannan, 2018; Gupta & Barua, 2017). Entre los métodos de evaluación de PV se encuentran el análisis envolvente de datos, modelado

estructural interpretativo, modelos deterministas de múltiples atributos, programación matemática, proceso analítico jerárquico (AHP), Fuzzy goal programming, TOPSIS, VIKOR, entre muchos otros (Luthra, Govindan, Kannan, Mangla, & Garg, 2017).

Y en cuanto a los atributos el proceso de selección y evaluación significará una comparación de los atributos relevantes para la toma de decisiones (Dobos & Vörösmarty, 2018). Ya que los atributos no son igualmente importantes, y los atributos o grupos de atributos desempeñan diferentes roles en la evaluación; Esto plantea desafíos a los investigadores y gerentes que buscan identificar los atributos más significativos. Más sin embargo, hoy en día el uso de los atributos es uno de los métodos más utilizado debido a cada organización podrá seleccionar los atributos que mejor le convengan.

Las organizaciones deben tener en cuenta múltiples atributos relacionados con los PV potenciales (por ejemplo, precio, tiempo de entrega), con el producto (por ejemplo, calidad, materiales) y, más recientemente, con aspectos relacionados con el medio ambiente y la sociedad (por ejemplo, la generación de contaminantes en las operaciones de producción y transporte, responsabilidad social, diseño verde, etcétera) (Hamdan & Cheaitou, 2017b).

En conclusión la selección final de PV requerirá la incorporación de atributos ambientales y tradicionales en las prácticas y enfoques de selección de un PV. El precio, la calidad y el nivel de servicio son los criterios de selección de proveedores tradicionales predominantes, mientras que la imagen verde, las emisiones, la eficiencia energética, la producción limpia y las iniciativas de reciclaje han sido las medidas ambientales más comunes (Gupta & Barua, 2017).

Así pues el uso de atributos en la evaluación y selección de un PV está altamente asociado a la obtención de beneficios ya que la selección correcta de un PV tiene un papel importante en ayudar a una empresa a lograr los máximos beneficios ecológicos y económicos (Luthra, Garg, & Haleem, 2015).

1.2.2 LA MANUFACTURA VERDE

La manufactura industrial es un sector sin duda importante para muchos países industrialmente emergentes como, India, China y México; y es vital para la creación de empleo y la economía de estos países. La manufactura contribuye a la economía, a través de sus relaciones sinérgicas con otros sectores como la minería, comercio, CS, servicios financieros e incluso con el sector de servicios (Thurner & Roud, 2016).

El vínculo entre la manufactura y el medio ambiente está siendo cada vez mayor, debido a que la MV es un paso clave para lograr la eliminación del consumo ineficiente de recursos, la reducción de emisiones nocivas y el reciclaje de materiales y el gran objetivo de la integración del pensamiento verde en la CS (Bonvoisin, Stark, & Seliger, 2017), ya que el progreso de la manufactura industrial lograra un aseguramiento, crecimiento y desarrollo económico sostenible a través de un enfoque ambientalmente viable como la implementación exitosa de la MV (Zhihong Wang & Sarkis, 2017).

Los MV es mucho más que hacer un buen producto o proceso de fabricación. El pensamiento verde en la fabricación se asocia comúnmente con el producto o las prácticas, o ambos, incluidos los procesos que no dañan el medio ambiente. La MV se asocia principalmente con el enfoque holístico de la compañía y considera el negocio completo, incluida la fabricación y la gestión de la CSV (Seth, Rehman, & Shrivastava, 2018).

La MV implica el diseño ecológico de los productos, el uso de materias primas y empaques respetuosos con el medio ambiente, la distribución y la reutilización después de la vida útil del producto. Cubre temas de fabricación, incluidos 6 R's, es decir, reducción, reutilización, reciclaje, recuperación, rediseño y remanufactura de recursos de conservación, gestión de residuos, protección ambiental, cumplimiento normativo, control de contaminación y otros requisitos relacionados (Govindan, Diabat, & Madan Shankar, 2015).

Sin embargo, implementar un proceso de MV no es tarea fácil, ya que se debe cumplir con regulaciones y políticas estrictas (Govindan et al., 2015). Ya que en estos momentos la manufactura industrial ocupa los primer lugar en consumo de energía y contaminación, siendo responsable del 84% de las emisiones de CO₂ y también del consumo del 90% de la energía (Kara, Singh, Philip, & Ramkumar, 2015).

Por lo anterior a movilizado a la industria manufacturera a buscar una forma rápida, fácil y sencilla para identificar de manera rápida y sencilla si su proceso de manufactura cumple con las características que lo avalen como un proceso de MV. Y han encontrado el uso de atributos como medida para la evaluación un proceso de manufactura o para valorar que tan verde puede llegar a ser en un determinado momento un proceso de manufactura.

Se están usando atributos tales como; reducción de emisiones y desechos al medio ambiente, conservación de la energía, agua y materiales, la certificación ambiental, producción limpia, generación de productos verdes, usos de tecnologías y la logística inversa (Charmondusit, Gheewala, & Mungcharoen, 2016; Teles, Ribeiro, Tinoco, & ten Caten, 2015).

Otros autores están usando atributos tales como; la innovación ambiental basados en la innovación tecnológica, los sistemas de monitorización medio ambiental y la colaboración ambiental del cliente (Grekova, Calantone, Bremmers, Trienekens, & Omta, 2016; Sáez-Martínez, Lefebvre, Hernández, & Clark, 2016; Sun, Miao, & Yang, 2017); prácticas verdes, diseño verde, compras o comercialización verdes, envases verdes, transporte ecológico, gestión de la CSV, entre muchos otros (Chan, Yee, Dai, & Lim, 2016; Jayaram & Avittathur, 2015; Qian & Soopramanien, 2015)

Además de que con el uso de los atributos, se ha encontrado que existen impactos positivos en el desempeño ambiental, comercial, económico, operativo y social en la organización; reduciendo los costos de materias primas, energía y mano de obra, agregando valor al producto, mejorando la eficiencia de producción, aumento de cuota de mercado, imagen social de la empresa y minimización de residuos y contaminación (Saufi, Daud, & Hassan, 2016; M. Singh, Brueckner, & Padhy, 2015; Thanki, Govindan, & Thakkar, 2016).

Igualmente, se producen sustanciales mejoras en la organización y la tecnología, ayudan a reducir el uso de recursos y sugerir mejores opciones en el uso de materiales y energía alternas (Lean et al., 2016; Sun et al., 2017), eliminando la generación de aguas residuales, emisiones gaseosas y calor y ruidos residuales (Pampanelli, Found, & Bernardes, 2014).

1.2.3 TECNOLOGÍAS DE INFORMACIÓN Y COMUNICACIÓN

Las TIC han sido reconocido cada vez más importante para garantizar el desarrollo sustentable. Desde los 2000's, las TIC se han convertido en un jugador esencial en el camino hacia una pensamiento verde (Gunasekaran, Subramanian, & Papadopoulos, 2017).

Las TIC se están usando tanto para mejorar el monitoreo del medio ambiente y las actividades humanas (en la industria, la construcción, el transporte, etc.) como para distribuir sistemas de TIC inteligentes para mitigar la contaminación, residuos, problemas de calidad, restricciones energéticas, etcétera (Klimova et al., 2016).

Igualmente la literatura sugiere que la TIC ha revolucionado a la logística y CS tradicional logrando numerosos beneficios, como mayor eficiencia y capacidad de respuesta. Ya que las prácticas de la CSV implican la comunicación y la coordinación de todos los involucrados en la CSV con respecto a la adopción de acciones de gestión verde por parte de una determinada organización y para facilitar ese proceso, las empresas están integrando las TIC en sus CSV(Gunasekaran, Subramanian, & Rahman, 2015).

Como se ha visto la implementación de una CSV implicará minimizar y preferiblemente, eliminar los efectos negativos de la CS tradicional sobre el medio ambiente. Sin embargo, también las herramientas usadas en la CSV deben de estar relacionadas con el nivel tecnológico, innovación y actualización; por lo cual el uso de las TIC debe impactar de manera positiva al medio ambiente y producir un efecto positivo en el diseño, inclusive en el procesos de productos verdes dentro de un CSV (Uygun & Dede, 2016).

Por lo cual las TIC en la CSV permitirán el intercambio de información en tiempo y forma mediante el uso de sistemas de red inteligentes de comunicación, tales como internet, intranet, Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), entre otros, mismas que son utilizados por todos los miembros de la CSV y permiten mejorar la eficiencia, las practicas verdes, reducir costo e inventarios (Khan, Hussain, & Saber, 2016).

En este contexto, el uso de las TIC para la implementación de una CSV permite desarrollar sistemas informáticos, fabricación orientada al servicio, productos inteligentes, controles robustos de producto, inteligencia ambiental, optimización, conciencia energética y sistemas autoorganizados para el monitoreo ambiental (Khan et al., 2016); los cuales están ayudando a proporcionar soluciones nuevas que ayudan a solventar los desafíos que se presentan en una CSV (Trentesaux, Borangiu, & Thomas, 2016).

Por tanto el uso de las TIC en un CSV ha sido de gran ayuda para agilizar el proceso de transformación de una CS tradicional a una CSV, ya que la inversión en TIC está ligada al crecimiento no solamente de una empresa, sino también al crecimiento de la economía de su CSV (Jorgenson & Vu, 2016), pero también se obtendrá beneficios en las empresas en función del nivel tecnológico asociados con aspectos de la productividad y se observa una gran ventaja en las tecnologías de reciente creación (Chung, 2017).

Igualmente la actualización y nivel tecnológico de las TIC permite que el intercambio de información entre los integrantes de la CSV sea rápido y sencillo, ya que permite integrar funciones de negocio tanto internas como externas. Además, aumenta el retorno de la inversión por la innovación de los procesos e incrementa las ventas y se verá el impacto ambiental y sustentable desde las perspectivas de desarrollo económico, ambiental y social (Chin et al., 2015).

1.3 BENEFICIOS DE TENER UNA CADENA DE SUMINISTROS VERDES

Las inversiones ambientales son la cantidad de capital asignado del presupuesto total de las organizaciones para mejorar y mantener el desempeño ambiental de las organizaciones. Esta asignación se puede utilizar ya sea durante la fase de diseño del producto, la fase de producción o durante la fase de eliminación, también se realizan inversiones para mejorar las tecnologías, la reducción de contaminantes y por su puesto para implementar una CSV (Al-Sheyadi et al., 2019).

Y uno de los principales propósitos de la adopción de prácticas verdes como la CSV es reducir los desechos y uso de recursos en relación con la sostenibilidad ambiental y ecológica. Sin embargo, es probable que algunas organizaciones crean que una CSV puedan aumentar los costos por adoptar este tipo de prácticas (Fang & Zhang, 2018).

Muchas organizaciones consideran a la CSV como un tema estratégico importante y que integra medidas ambientales en CS. Y la CSV llega a ser importante para las organizaciones y empresas para mejorar las ventajas competitivas, la participación de mercado y la rentabilidad como una estrategia de negocio que está estrechamente relacionada con la responsabilidad social corporativa con un impacto positivo en el desempeño económico y ambiental de la organización (Lee, Ooi, Chong, & Seow, 2014).

Además se ha comprobado que el implementar una CSV en una organización si conlleva una serie de beneficios, ya que este proceso es crucial para fomentar el pensamiento verde organizacional (Geng, Mansouri, & Aktas, 2017), ya que actualmente se tienen que mantener niveles adecuados de competitividad y al mismo tiempo cumplir con requisitos gubernamentales, ambientales y sociales.

Algunos beneficios asociados con la implementación de un CSV pueden ser ambiental, comercial, económico, operativo y social. Así mismo, la CSV producen sustanciales mejoras en la organización ayudando a reducir el uso de recursos y sugerir mejores

opciones en el uso de materiales y energía alternas (Lean et al., 2016), eliminando la generación de aguas residuales, emisiones gaseosas y ruidos residuales, entre muchos otros (Pampanelli et al., 2014).

Conjuntamente la CSV ayuda a la reducción de los costos de materias primas, energía y mano de obra, agregando valor al producto, mejorando la eficiencia de producción, aumento de cuota de mercado, imagen social de la empresa, minimización de residuos y contaminación (Thanki et al., 2016).

Sin embargo, es necesario resaltar que el beneficio más valorado por todos los investigadores es el del factor económico (Jabbour & de Sousa Jabbour, 2016), ya que existe una relación significativa entre la reducción de emisiones y la mejora en el desempeño financiero, generando ganancias económicas a corto y largo plazo (Neumüller, Lasch, & Kellner, 2016).

Por lo cual la adopción de una CSV conlleva la obtención de una serie de beneficios (Brandenburg, Govindan, Sarkis, & Seuring, 2014). Sin embargo, para obtener una implementación exitosa de una CSV; la participación de los PV, MV y las TIC serán muy importantes para lograrla (Luthra, Garg, & Haleem, 2016) y a su vez las asociaciones sólidas con éstos ayudan la obtención de más beneficios relacionados con el medio ambiente (Awasthi & Kannan, 2016).

1.4 PROBLEMA DE INVESTIGACIÓN

Se puede ver que la CSV es un tópico muy importante y presentado por diferentes investigadores en contextos incluyendo países diferentes; más sin embargo en la industria maquiladora mexicana aun es un tema muy poco conocido y prácticamente con un nulo desarrollo en la investigación.

Debido a lo anterior se desconoce el impacto y la importancia de contar con una CSV para la industria maquiladora mexicana y para un país en desarrollo industrial y terceromundista como México, que aun los tópicos verdes, sustentables y el cuidado ambiental no son prioritarios.

Sin embargo, hoy en día la CSV más que una ventaja competitiva, diferenciación o algo novedoso, en estos momento debe ser una obligación para cualquier país o tipo de industria, debido a que la globalización, el consumo excesivo de productos manufacturados, la poca conciencia ambiental y el desconocimiento de que la CSV más que un gasto o algo difícil de implementar. Es una inversión que redituara de manera positiva y significativa a lo largo de toda la cadena y de sus integrantes.

Por lo cual esta investigación busca dejar un precedente para la industria manufacturera mexicana y de otros países descubran que hoy en día contar con una CSV no es algo imposible o complicado de implementar, más bien es una oportunidad de optimizar su

organización, CS y sobre todo brindarle un mejor producto al cliente y sobre todo reduciendo el impacto social, ambiental y económico que se genera al no contar con una CSV.

Además es importante recalcar que una CSV no solo sirve para integrar un pensamiento verde y sustentable en esta, si no que la CSV exitosamente implementada, genera una serie de beneficios económicos, sociales, operativos y por su puesto ambientales que se verán reflejados a lo largo de la organización, clientes, participes de la cadena y por supuesto en el medio ambiente.

1.5 OBJETIVOS

Los objetivos principales de esta investigación son los siguientes:

- Identificar los atributos tradicionales y verdes más importantes para la selección y evaluación de un PV y los beneficios que se obtiene al contar con un PV en una CSV, haciendo uso de un modelo de ecuaciones estructurales.
- Determinar el impacto que tiene el uso y la actualización de las TIC en la implementación y beneficios ganados al contar con un CSV, usando un modelo de ecuaciones estructurales.
- Identificar cuáles son los atributos más importantes para evaluar a un proceso de MV, además de relacionar estos atributos con los beneficios que se generar en la CSV cuando se implanta un proceso de MV, usando el modelado de ecuaciones estructurales.
- Cuantificar los beneficios que tiene implementar un CSV en la manufactura industrial utilizando a los PV, la MV y las TIC.

1.6 CONTEXTO DE INVESTIGACIÓN

La investigación desarrollada muestra la importancia que hoy en día tiene contar con una CSV en cualquier tipo de industria y en cualquier país del mundo ya que con las cuestiones climáticas, medioambientales, regulaciones ambientales mundiales y la responsabilidad social tanto de consumidores y cliente final, en estos tiempos no contar con un CSV es estar fuera del mercado competitivo y mundial.

Se presenta tres factores muy importantes para facilitar la implementación de una CSV, factores como: los PV, el uso de las TIC y los proceso de MV y no solo eso, además se comprueba cuantitativamente que al involucrar estos tres factores en un CSV se generaran una serie de beneficios, operativos, de procesos, comerciales, y económicos.

1.7 LIMITACIONES Y DELIMITACIONES

Estas investigaciones se llevaron a cabo en industria manufacturera mexicana ubicada en ciudades fronterizas con Estados Unidos de América, utilizando la metodología del modelado de ecuaciones estructurales basada en mínimos cuadrados parciales, por lo que se pueden tener las siguientes limitantes:

- En relación con los modelos propuestos para el sector industrial manufacturero mexicano, dadas las singularidades que ésta tiene al ser plantas filiales de otras establecidas en diferentes países, así como de las condiciones económicas, sociales y culturales del país, su aplicación e implementación puede llegar a pensarse que su validez es solamente en la región.
- En cuanto a la selección de un proveedor con el uso de atributos, es importante recalcar que en esta investigación solo se utilizaron algunos de los muchos que hay existen y que se van descubriendo día a día, por lo cual la obtención de los beneficios que aquí se presentan están limitados al uso de los atributos utilizados para la investigación.
- En cuanto al uso y actualización de las TIC para la implementación de una CSV, cabe señalar que se presenta solo la TIC con las que se cuenta en el área de estudio, por lo cual un país más desarrollado tecnológicamente hablando podrá ganar más beneficios.
- En cuanto a la evaluación de un proceso de MV con el uso de atributos, es importante recalcar que en esta investigación solo se utilizaron algunos de los muchos que existen y que se van descubriendo día a día, por lo cual la obtención de los beneficios que aquí se presentan están limitados al uso de los atributos utilizados para la investigación.
- No obstante, todos los resultados y las metodologías aplicadas en investigación, que por su carácter científico y pedagógico se explican a detalle, pueden considerarse como casos de estudio o prácticos y pueden servir como base metodológica en otros estudios a las que se quiera extrapolar su aplicación.

2. METODOLOGÍA

En el siguiente apartado se muestra la metodología que se ha llevado a cabo en esta investigación.

2.1 ELABORACIÓN DE LA ENCUESTA

Una encuesta es un conjunto de preguntas o ítems planteados de forma interrogativa, enunciativa, afirmativa o negativa con varias alternativas, en un formato determinado, un orden de preguntas y un contenido concreto sobre el tema que se desea investigar. La encuesta ayudar a obtener la información necesaria, cuando la investigación tiene como objetivo conocer la opinión de una gran cantidad de personas de manera rápida, sencilla y eficiente (N. Singh, Jain, & Sharma, 2015).

El diseño de la encuesta se basa en revisiones de literatura hechas en distintas bases de datos como; Springer, Sciendirect, Taylor and Francis, entre otras; además esta revisión de literatura representa una validación racional del cuestionario y cada uno de los ítems que integran al mismo.

Para aumentar la validez aparente, la encuesta que se desarrolla inicialmente se le realiza una prueba piloto a diferentes encuestados, prueba que sirve para debido a que los ítems de la encuesta se obtuvieron a partir de investigaciones realizadas en diferentes países y sectores industriales, un grupo de expertos en la CSV, incluidos académicos, gerentes e ingenieros que trabajan en organizaciones, evaluaron la congruencia, relevancia, importancia y lenguaje de esta. Este proceso representa la validación de los jueces y ayudó a adaptarlo al contexto de la industria manufacturera.

Las encuestas utilizadas están divididas en dos secciones, la primera sección consta de una serie de preguntas demográficas como; puesto del encuestado, años de experiencia, género del encuestado, etcétera, dichas preguntas nos servirán para conocer más a fondo datos específicos de los encuestados y poder hacer una caracterización de nuestra muestra.

La segunda sección consta de una serie de tablas donde se muestran los ítems o preguntas definidas y que están relacionadas con tópicos específicos y generales de esta investigación la CSV. Los ítems deben responderse en una escala de Likert con valores entre uno y cinco, donde el uno indica no importante o nunca y el cinco indica totalmente importante o siempre.

2.2 APLICACIÓN DEL CUESTIONARIO

La encuesta se aplica a la industria manufacturera Mexicana ubicada en ciudades fronterizas con Estados Unidos de América ya que estas representan el 55% de la industria manufacturera mexicana (IMMEX, 2019).

La aplicación se dirige a personas laborando en aquellos departamentos involucrados con la CSV, o que tengan una relación muy estrecha con la CSV, tales como: producción, procesos, ingeniería, logística, calidad, gerencia, almacén entre otros; por lo que el muestreo es estratificado inicialmente, aunque después se usa la técnica de la bola de nieve, ya que algunos encuestados recomiendan a otros colegas para contestar la encuesta. La aplicación de la encuesta se lleva a cabo mediante una entrevista personal y solo con personal con al menos un año de experiencia en su puesto con la finalidad de obtener información más fidedigna acerca de la CSV.

2.3 CAPTURA DE LA INFORMACIÓN Y DEPURACIÓN DE LA BASE DE DATOS

La información recolectada a través de las encuestas aplicadas se analiza y capturada en el software estadístico llamado SPSS 24®, un programa estadístico informático muy usado en análisis de información y bases de datos de tamaño de muestras grandes que tiene un sencillo interfaz para la mayoría de los análisis. En la base de datos construida, los renglones representan los casos y las columnas representan los ítems o variables observadas que componen a las variables latentes.

La base de datos ya completa se depura antes de realizar cualquier análisis y las principales acciones son (Iacobucci, Posavac, Kardes, Schneider, & Popovich, 2015):

- Identificar valores perdidos o que no fueron contestados en la encuesta. Si el porcentaje de valores perdidos es menor al 10%, entonces se reemplaza por la mediana del ítem; sin embargo, si el porcentaje es mayor, esta encuesta es eliminada.
- Identificar valores extremos o atípicos en cada ítem y reemplazarlo por la mediana, ya que los valores obtenidos están en una escala Likert.
- Identificar encuestados no comprometidos mediante la estimación de la desviación estándar de los ítems en la encuesta. Encuestas con desviación estándar menor a 0.35 son eliminadas debido a la falta de respuestas validas por parte del encuestado.

2.4 VALIDACIÓN ESTADÍSTICA

Para que se hable de que el instrumento es idóneo, y que se pueda utilizar con toda la confianza se requiere que cumpla con dos requisitos: confiabilidad y validez. Esto indica si un instrumento mide de forma adecuada las variables que se pretenden evaluar con facilidad y eficiencia(Jajja et al., 2018). La validez, en términos generales, se refiere al grado en que un instrumento realmente mide la variable que pretende medir. El término confiabilidad define la probabilidad de éxito de un sistema, el cual necesariamente debe depender de la confiabilidad o el éxito de sus componentes.

Una vez depurada la información, se valida mediante diferentes índices. Los índices que se miden en cada variable latente son:

- R^2 y el R^2 ajustada para medir la validez predictiva, esta validez nos sirven para indicar que esa variable predice lo que nosotros esperamos del modelo y se requieren valores superiores a 0.2 (Sen, Roy, & Pal, 2015) y sólo se presenta para las variables dependientes y representa la cantidad de varianza que es explicada en la variable dependiente por el conjunto de variables independientes.
- Q^2 para medir la validez predictiva no paramétrica y se utiliza este índice debido a que los datos carecen de un apego a una distribución normal, la cual es una condición exigida en análisis de regresión; al igual que los índices R^2 y R^2 ajustada se esperan valores mayores a 0.2 y sólo es reportada para las variables independientes (Chan et al., 2016).
- Alfa de Cronbach e Índice de confiabilidad compuesta sirve para medir la fiabilidad interna y donde se asume que los ítems (medidos en escala tipo Likert) miden un mismo constructo y que están altamente correlacionados (Welch, 1988) y requieren valores superiores a 0.7 (Han, Wang, & Naim, 2017). Estos índices se obtienen de manera iterativa, ya que muchas veces al eliminar algunas actividades o beneficios, se incrementan los valores de estos.
- Varianza promedio extraída (AVE) para medir la validez convergente, una buena validez convergente es si los encuestados entienden las preguntas o ítems que fueron definidas en las encuestas y han sido asociadas con cada variable latente y se requieren valores mayores a 0.5 (Zailani, Govindan, Iranmanesh, Shaharudin, & Sia Chong, 2015).

2.5 ANÁLISIS DESCRIPTIVO DE LA INFORMACIÓN Y DE LA MUESTRA

Se realizan dos tipos de análisis descriptivos. El primer análisis descriptivo se hace en la información y este se refiere al análisis de los ítems o preguntas que componen al cuestionario. Se usa la mediana como medida de tendencia central ya que los datos obtenidos son ordinales.

Altos valores en la mediana indican que la actividad siempre es realizada o que el beneficio siempre es obtenido, mientras que valores bajos indican que la actividad no es realizada dentro de la CSV y que los beneficios no son obtenidos como consecuencia de la CSV.

Se usa el rango intercuartílico como medida de dispersión de los datos, por lo que se estima el primer cuartil (25) y tercer cuartil (75) en cada una ítem y la resta del tercero menos el primer cuartil nos dará el rango intercuartílico, al igual que la mediana el rango

intercuartílico es usado debido a la escala Likert con que fueron obtenidos los datos en la encuesta.

Valores altos en el rango intercuartílico indican que señalan un desacuerdo en relación con el verdadero valor medio que tiene dicho ítem, pero si el rango intercuartílico tiene valores bajos, indican un adecuado consenso entre los encuestados en relación con el ítem.

2.6 DISEÑO DE UN MODELO DE ECUACIONES ESTRUCTURALES

Las ecuaciones estructurales basadas en mínimos cuadrados parciales, es una técnica de análisis multivariante utilizada y aplicada en las validaciones de relaciones causales y específicamente con el tema relacionado con la CSV (Jajja et al., 2018; Zhiqiang Wang, Wang, Zhang, & Zhao, 2018).

En esta investigación se usa la técnica de ecuaciones estructurales integrada en el software WarpPLS 6.0®, para definir una serie de modelos con la información obtenida con la aplicación de las encuestas, estas encuestas se volverá ítems, y los ítems a su vez conformaran a las variables latentes, en WarpPLS 6.0® sus algoritmos están basados en mínimos cuadrados parciales, ampliamente recomendado para bajo tamaño de la muestra (Kock, 2016).

Se consiguen seis índices de calidad y ajuste del modelo, las cuales son los siguientes (Kim & Chai, 2017; Sreedevi & Saranga, 2017):

- coeficiente promedio de trayectoria (APC), el promedio de R-cuadrada (ARS) y el promedio de R-cuadrada ajustada (AARS) que requieren p valores asociados menores a 0.05 y que se utiliza para medir la validez predictiva del modelo.
- El factor de inflación de la varianza media (AVIF) y el índice promedio de colinealidad (AFVIF) que requiere valores menores a 5, para determinar que el modelo no tiene problemas de multicolinealidad.
- Índice de Tenenhaus GoF (GoF) que mide el ajuste de los datos al modelo y se requieren valores mayores a 0.36 y se utiliza para medir el ajuste de los datos al modelo.

Posteriormente, se miden tres tipos diferentes de efectos en el modelo, a los cuales se les asocia un valor de β que representa la intensidad de cambio entre las variables latentes independientes y dependientes expresado en desviaciones estándar.

Los efectos medidos en el modelo de ecuaciones estructurales son: (1) el efecto directo que sirve para validar las hipótesis definidas previamente y se representa mediante fechas de una variable a otra, (2) la suma del efecto indirectos que se da cuando existen variables mediadoras y requiere de dos o más segmentos y (3) los efectos totales que representa simplemente la suma de los efectos directos más los efectos indirectos.

La validación estadística de todos los tipos de efectos se lleva a cabo mediante una prueba de hipótesis, donde la hipótesis nula se representa por $\beta_i = 0$, contra la hipótesis alternativa de que $\beta_i \neq 0$ (Ağan, Kuzey, Acar, & Açıkgöz, 2016), donde se busca probar la hipótesis alternativa para demostrar que la relación entre las variables latentes no es trivial.

Es significativo mencionar que en los modelo, se observa que algunas de las variables latentes dependientes son explicadas por dos o más variables, por lo que en esta investigación se presenta el valor de R^2 , la cual representa la porción de varianza que explique cada una de las variables independientes, a lo que se le llama tamaño de los efectos (ES), lo que permite identificar las variables esenciales de las triviales.

2.7 ANÁLISIS DE FIABILIDAD

Ordinariamente se puede requerir realizar un análisis de sensibilidad para conocer el efecto que tiene el cambio de una variable independiente en una variable dependiente. Y dado que se hace uso de ecuaciones estructurales basadas en mínimos cuadrados parciales, los valores de las variables latentes se encuentran estandarizados y es posible estimar probabilidades de ocurrencia entre ellas.

En este caso, se asume que un valor estandarizado mayor a 1 (>1) representa una probabilidad “alta” de ocurrencia, mientras que un valor menor a menos 1 (-1) representa una probabilidad “baja” de ocurrencia, por lo que para cada una de las hipótesis se realiza un análisis de los cuatro estadios que pueden tener las variables.

Específicamente, en este estudio se analizan las probabilidades de ocurrencia de manera simultánea en cada uno de los estadios y se representa por “&”, mientras que la probabilidad condicional se representa por “if”.

3. RESULTADOS

Se muestran tres estudios de investigación, teniendo como tema principal la CSV y los beneficios en su implementación en la industria manufacturera mexicana ubicada en ciudades fronterizas con Estados Unidos de América, usando el modelado de ecuaciones estructurales como metodología principal.

- El papel de los atributos verdes y atributos tradicionales de los proveedores en el rendimiento empresarial.
- El papel de las tecnologías de la información y la comunicación en la implantación de la cadena de suministro verde y en el rendimiento de las empresas.
- El papel de los atributos verdes en los procesos de producción, así como su impacto en los beneficios operativos, comerciales y económicos.

Los resultados citados antes se describen brevemente a continuación.

3.1 EL PAPEL DE LOS ATRIBUTOS VERDES Y ATRIBUTOS TRADICIONALES DE LOS PROVEEDORES EN EL RENDIMIENTO EMPRESARIAL.

Los resultados de este estudio se presentan de manera ordenada, donde se inicia con la definición de las hipótesis de trabajo, modelo inicial, la validación de las hipótesis, el modelo final, los efectos del modelo y algunas aportaciones teóricas en base a los resultados del modelo.

Las hipótesis de la investigación se definen a continuación y que se presentan gráficamente en la Figura 1:

- H_1 : Los *Atributos Tradicionales* utilizados en la evaluación de un proveedor tienen un efecto directo y positivo en los *Atributos Verdes* que pueden ser utilizados para evaluar en un proveedor.
- H_2 : Los *Atributos Tradicionales* utilizados en la evaluación y selección de un proveedor tienen un efecto directo y positivo en los *Beneficios en los Procesos Productivos* que pueden obtener las empresas.
- H_3 : Los *Atributos Verdes* utilizados en la evaluación de un proveedor tienen un efecto directo y positivo en los *Beneficios en los Procesos Productivos* que se pueden llegar obtener.

- H₄: Los *Atributos Tradicionales* utilizados en la evaluación de un proveedor tienen un efecto directo y positivo en los *Beneficios de Comercialización* que se pueden llegar obtener con la selección de este.
- H₅: Los *Atributos Verde* utilizados en la evaluación de un proveedor tienen un efecto directo y positivo en los *Beneficios de Comercialización* que se pueden llegar obtener con la selección de este.
- H₆: Los *Beneficios en los Procesos Productivos* obtenidos en la selección de un proveedor tienen un efecto directo y positivo en los *Beneficios de Comercialización* que se pueden llegar obtener con la selección de este.

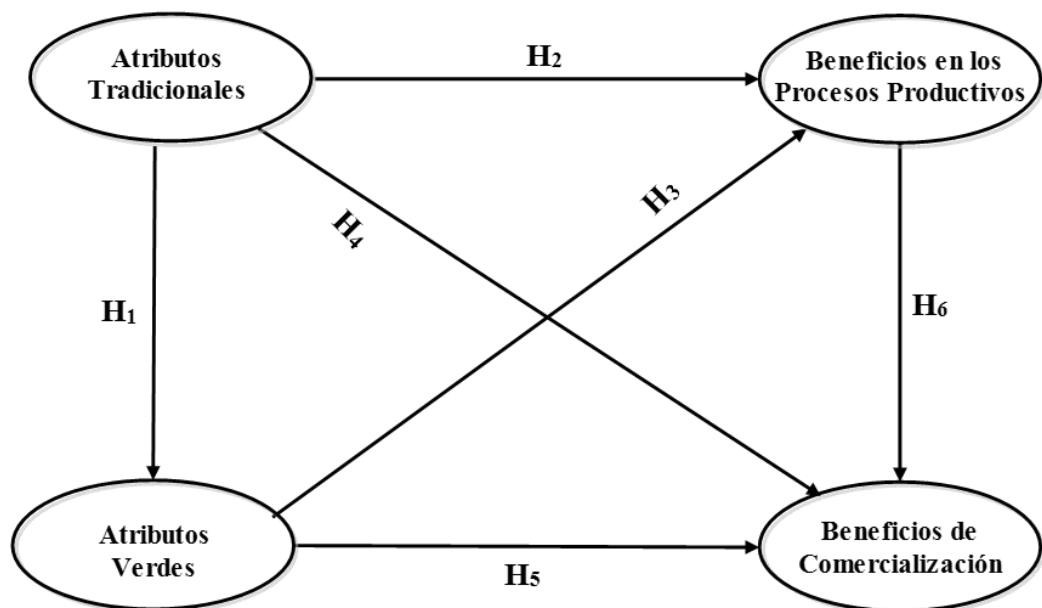


Figura 1. Hipótesis gráficas.

El modelo fue evaluado haciendo uso del software WarpPLS 5.0 ®, el cual utiliza la técnica de mínimos cuadrados parciales y que se presenta en la Figura 2.

Donde en cada uno de los segmentos que representa la relación entre dos variables latentes se indica con valor del parámetro beta (β) y el p-valor de la prueba estadística de significancia. Obsérvese también que en cada una de las variables latentes dependientes se indica un valor de R^2 para medir la cantidad de varianza que es explicada por las variables dependientes.

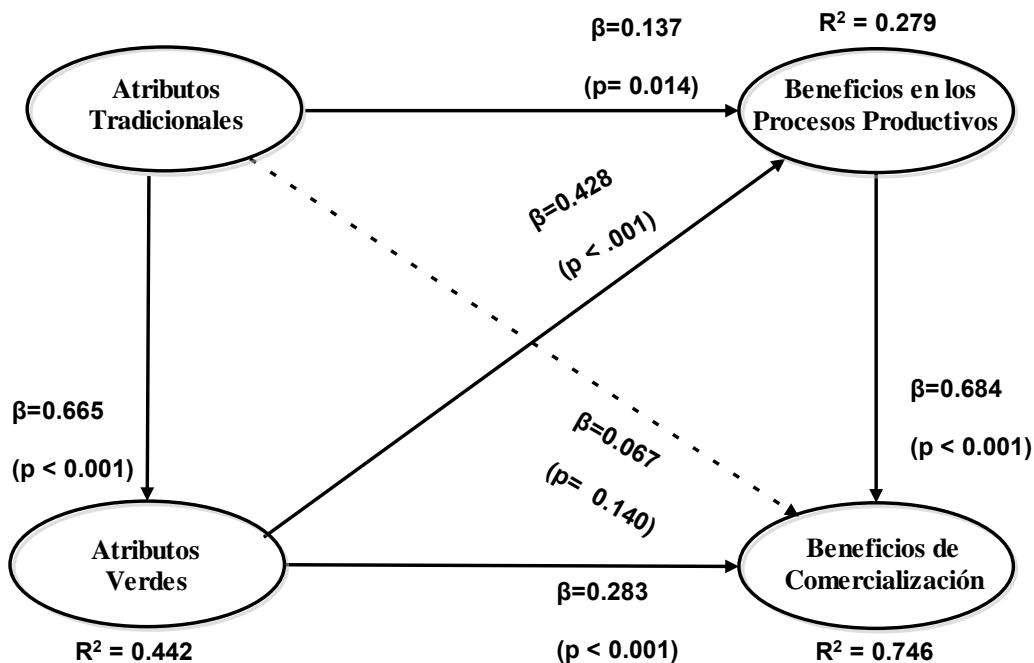


Figura 2. Modelo final.

Con la ejecución del modelo en el software se ha llegado a la validación o no de las hipótesis definidas y que a continuación se presentan:

- H_1 : Los *Atributos Tradicionales* tienen un efecto directo y positivo en los *Atributos Verdes* que son considerados en la selección de un proveedor en la industria manufacturera.
- H_2 : Los *Atributos Tradicionales* tienen un efecto directo y positivo en los *Beneficios en los Procesos Productivos* que se pueden obtener con la selección correcta de un proveedor en la industria manufacturera.
- H_3 : Los *Atributos Verdes* tienen un efecto directo y positivo en los *Beneficios en los Procesos Productivos* que se pueden obtener con la selección correcta de un proveedor en la industria manufacturera.
- H_4 : Los *Atributos Tradicionales* no tienen un efecto directo y positivo en los *Beneficios de Comercialización* que se pueden obtener con la selección correcta de un proveedor en la industria manufacturera.
- H_5 : Los *Atributos Verdes* tienen un efecto directo y positivo en los *Beneficios de Comercialización* que se pueden obtener con la selección correcta de un proveedor en la industria manufacturera.

- H_6 : Los *Beneficios en los Procesos Productivos* tienen un efecto directo y positivo en los *Beneficios de Comercialización* que se pueden obtener con la selección correcta de un proveedor en la industria manufacturera.

El modelo cuenta con diferentes tipos de efectos los cuales se presentan en la tabla 1.

Tipo de Efecto	Desde	Hacia	
Indirecto	Atributos Tradicionales	Beneficios de Comercialización	0.478 (P < 0.001) ES = 0.193
	Atributos Tradicionales	Beneficios en los Procesos Productivos	0.284 (P < 0.001) ES = 0.119
	Atributos Verdes	Beneficios en los Procesos Productivos	0.292 (P < 0.001) ES = 0.174
Total	Atributos Tradicionales	Atributos Verdes	0.665 (P < 0.001) ES = 0.442
	Atributos Tradicionales	Beneficios en los Procesos Productivos	0.421 (P < 0.001) ES = 0.177
	Atributos Tradicionales	Beneficios de Comercialización	0.545 (P < 0.001) ES = 0.220
	Atributos Verdes	Beneficios de Comercialización	0.579 (P < 0.001) ES = 0.343
	Atributos Verdes	Beneficios en los Procesos Productivos	0.428 (P < 0.001) ES = 0.222
	Beneficios en los Procesos Productivos	Beneficios de Comercialización	0.684 (P < 0.001) ES = 0.549

Tabla 1. Efectos del modelo.

Con base a los resultados encontrados en el modelo aquí generado, se pueden tener las siguientes aportaciones teóricas:

- La investigación muestra como los esfuerzos por obtener materias primas que provengan de un proveedor que cumpla todas las especificaciones son baldíos si no se pueden convertir en ventaja competitiva durante el proceso de producción. Esta conclusión se valida a través del impacto directo poco significativo (con un nivel de confianza del 95%) que los Atributos tradicionales tienen sobre los Beneficios de marketing.
- Otro aspecto importante para destacar es que los tributos tradicionales no son suficientes para tener un proceso productivo eficiente. El impacto directo que los Atributos tradicionales tienen sobre los Beneficios en los procesos de producción es menor que el efecto indirecto que esta variable tiene a través de la variable mediadora Atributos verdes.
- También, conviene señalar que el impacto directo que tienen los *Atributos Tradicionales* sobre los *Atributos Verdes* es alto. Afiración que se valida con la H_1 , lo que nos indica que hoy en día los *Atributos Tradicionales* continúan primando sobre los Atributos Verdes en la evaluación de proveedores.

- La investigación muestra como las empresas maquiladoras deben ser competitivas, desde el punto de vista del sistema de producción, para poder obtener ventajas comerciales. Siendo muy alto el impacto directo que tienen los *Beneficios en los Procesos de Producción* sobre los *Beneficios de Comercialización*.

3.2 EL PAPEL DE LAS TECNOLOGÍAS DE LA INFORMACIÓN Y LA COMUNICACIÓN EN LA IMPLANTACIÓN DE LA CADENA DE SUMINISTRO VERDE Y EN EL RENDIMIENTO DE LAS EMPRESAS.

Los resultados de este estudio se presentan de manera ordenada, donde se inicia con la definición de las hipótesis de trabajo, modelo inicial, la validación de las hipótesis, el modelo final, los efectos del modelo y algunas aportaciones teóricas en base a los resultados del modelo.

Las hipótesis de la investigación se definen a continuación y que se presentan gráficamente en la Figura 3:

- H₁: El proceso de *Integración de las TIC* tiene un efecto directo y positivo en el nivel de *Actualización de las TIC* dentro de una CSV.
- H₂: La *Integración de las TIC* tiene un efecto directo y positivo en la *Implementación CSV*.
- H₃: La *Actualización de las TIC* tiene un efecto directo y positivo en la *Implementación CSV*.
- H₄: La *Integración de TIC* tiene un efecto directo y positivo en la obtención de *Beneficios de CSV* con su implementación.
- H₅: La *Actualización de las TIC* tiene un efecto directo y positivo en la obtención de *Beneficios de CSV* con su implementación.
- H₆: La *Implementación de una CSV* tiene un efecto directo y positivo en la obtención de *Beneficios de CSV* con su implementación.

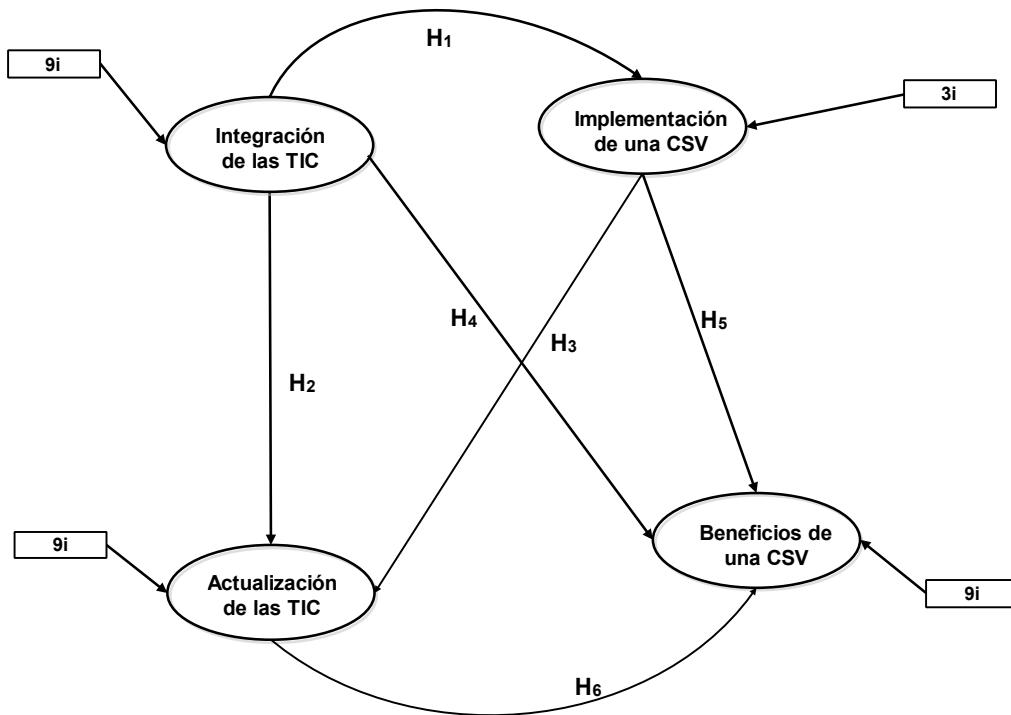


Figura 3. Hipótesis gráficas.

El modelo fue evaluado haciendo uso del software WarpPLS 6.0 ®, el cual utiliza la técnica de mínimos cuadrados parciales y que se presenta en la Figura 4.

Donde en cada uno de los segmentos que representa la relación entre dos variables latentes se indica con valor del parámetro beta (β) y el p-valor de la prueba estadística de significancia. Obsérvese también que en cada una de las variables latentes dependientes se indica un valor de R^2 para medir la cantidad de varianza que es explicada por las variables dependientes.

Con la ejecución del modelo en el software se ha llegado a la validación o no de las hipótesis definidas y que a continuación se presentan:

- **H₁:** La *Integración de las TIC* tiene un efecto directo y positivo en el nivel de *Actualización de las TIC* dentro de una cadena de suministro verde.
- **H₂:** La *Integración de las TIC* tiene un efecto directo y positivo en la *Implementación CSV*.

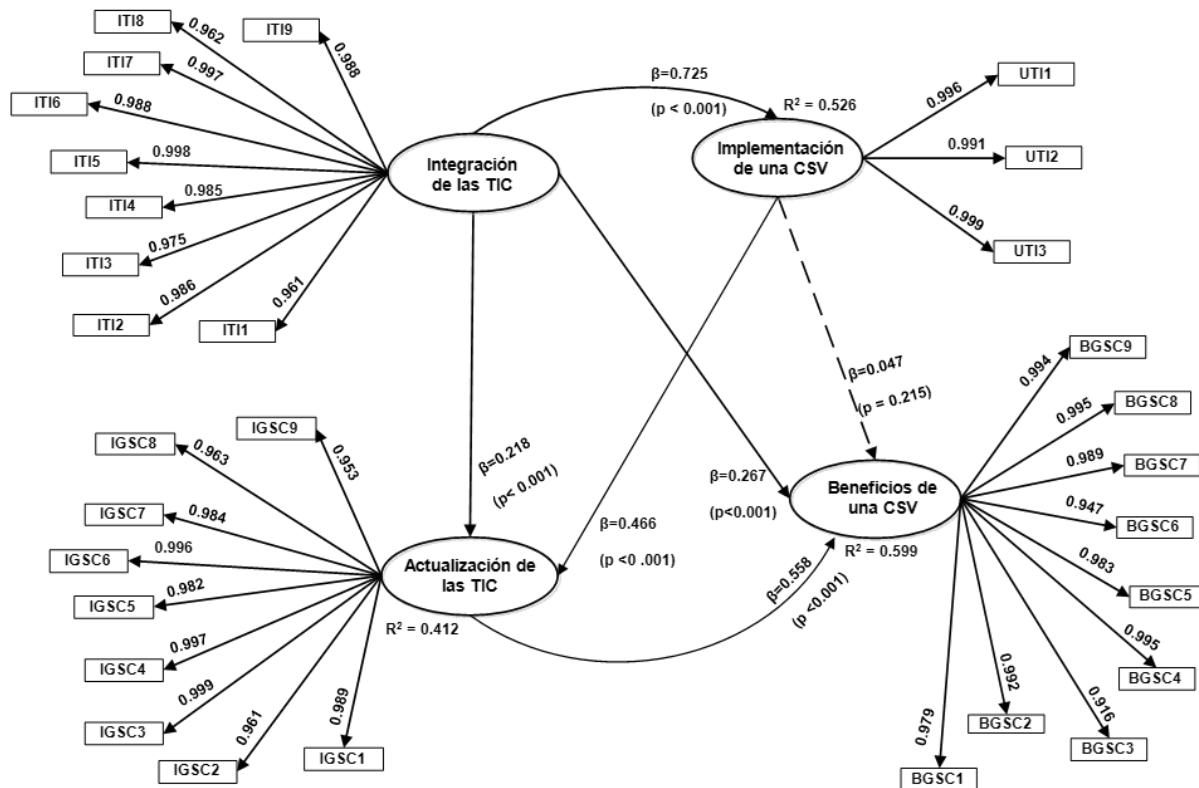


Figura 4. Modelo final.

- H₃: La *Actualización de las TIC* tiene un efecto directo y positivo en la *Implementación CSV*.
- H₄: La *Integración de TIC* tiene un efecto directo y positivo en la obtención de *Beneficios de CSV* con su implementación.
- H₅: La *Actualización de las TIC* no tiene un efecto directo y positivo en la obtención de *Beneficios de CSV* con su implementación.
- H₆: La *Implementación de una CSV* tiene un efecto directo y positivo en la obtención de *Beneficios de CSV* con su implementación.

El modelo cuenta con diferentes tipos de efectos los cuales se presentan en la tabla 2.

Tipo de Efecto	Desde	Hacia	
Indirecto	Integración de TIC	Implementación de una CSV	0.338 ($P < 0.001$) ES = 0.188
	Integración de TIC	Beneficios de CSV	0.334 ($P < 0.001$) ES = 0.209
	Actualización de las TIC	Beneficios de CSV	0.260 ($P < 0.001$) ES = 0.152

	Integración de TIC	Actualización de las TIC	0.725 (P < 0.001) ES = 0.526
	Integración de TIC	Implementación de una CSV	0.556 (P < 0.001) ES = 0.309
Total	Integración de TIC	Beneficios de CSV	0.611 (P < 0.001) ES = 0.372
	Actualización de las TIC	Implementación de una CSV	0.466 (P < 0.001) ES = 0.291
	Actualización de las TIC	Beneficios de CSV	0.307 (P < 0.001) ES = 0.179
	Implementación de una CSV	Beneficios de CSV	0.558 (P < 0.001) ES = 0.410

Tabla 2. Efectos del modelo.

Con base a los resultados encontrados en el modelo aquí generado, se pueden tener las siguientes aportaciones teóricas:

- En base a los resultados obtenidos, se observa que la *Integración de las TIC* y *Actualización de las TIC* están relacionadas, esto debido a que una complementa a la otra y esto se comprueba mediante H₁, ya que entre ambas variables existe el efecto directo más grande y significativo de todo el modelo.
- Igualmente, es de suma importancia subrayar que las TIC son una herramienta efectiva que facilita la implementación de una CSV. Esta afirmación se valida a través del efecto total y significativo que la variable latente *Integración de las TIC* tiene sobre la variable *Implementación de la CSV*.
- Aunque el efecto directo entre la *Actualización de las TIC* y los *Beneficios de las CSV* no es estadísticamente significativo H₅, el efecto indirecto si lo fue, por lo cual el efecto total también lo es. Por lo tanto, hoy en día usar las TIC con alto nivel tecnológico en la implementación y administración de una CSV es una prioridad estratégica.
- También, es importante el análisis que se obtiene de la relación que existe entre la *Integración de las TIC* en los *Beneficios de CSV*. El efecto directo fue de solamente 0.267 (ver Figura 4), pero el efecto indirecto fue de 0.334, mismo que es dado a través de la *Actualización de las TIC* y la *Implementación de la CSV* como variables mediadoras.

3.3 EL PAPEL DE LOS ATRIBUTOS VERDES EN LOS PROCESOS DE PRODUCCIÓN, ASÍ COMO SU IMPACTO EN LOS BENEFICIOS OPERATIVOS, COMERCIALES Y ECONÓMICOS.

Los resultados de este estudio se presentan de manera ordenada, donde se inicia con la definición de las hipótesis de trabajo, modelo inicial, la validación de las hipótesis, el

modelo final, los efectos del modelo y algunas aportaciones teóricas en base a los resultados del modelo.

Las hipótesis de la investigación se definen a continuación y que se presentan gráficamente en la Figura 5:

- H₁: Los *Atributos Antes y Durante un Proceso de Manufactura Verde* tiene un efecto directo y positivo en los *Beneficios Operativos* que se obtienen con la implementación de prácticas de MV.
- H₂: Los *Atributos Antes y Durante un Proceso de Manufactura Verde* tiene un efecto directo y positivo en los *Beneficios Comerciales* que se obtienen al implementar prácticas de MV en el proceso de producción

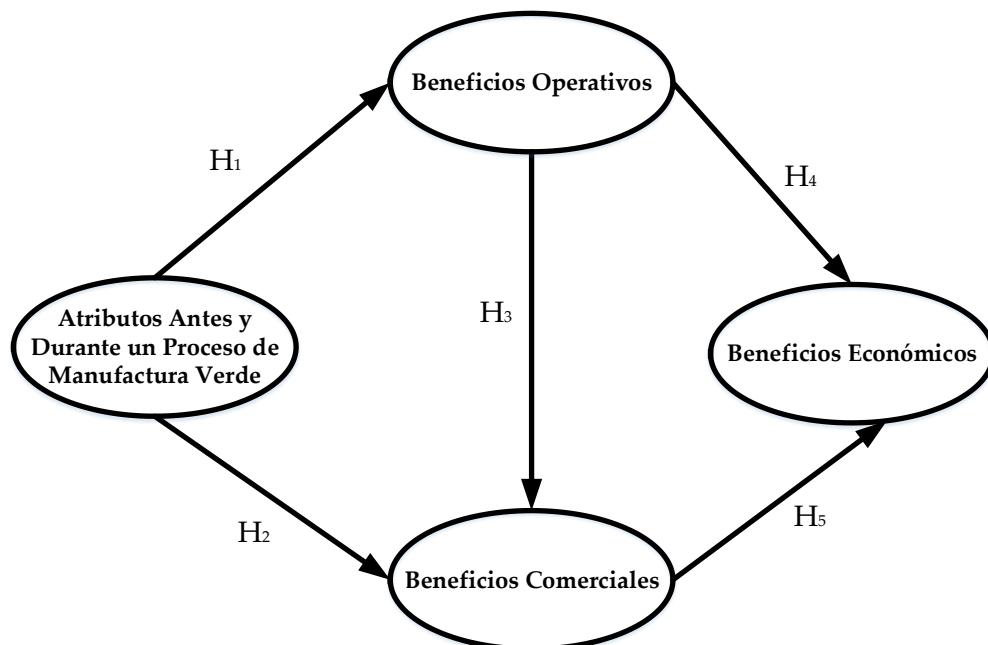


Figura 5. Hipótesis gráficas.

- H₃: Los *Beneficios Operativos* tiene un efecto directo y positivo en los *Beneficios Comerciales* que se obtienen al implementar prácticas de MV en las líneas de producción.
- H₄: Los *Beneficios Operativos* tiene un efecto directo y positivo en los *Beneficios Económicos* que obtienen con la implementación de un proceso de MV.
- H₅: Los *Beneficios Comerciales* tiene un efecto directo y positivo en los *Beneficios Económicos* que se obtienen con la implementación de un proceso de MV.

El modelo fue evaluado haciendo uso del software WarpPLS 6.0 ®, el cual utiliza la técnica de mínimos cuadrados parciales y que se presenta en la Figura 6.

Donde en cada uno de los segmentos que representa la relación entre dos variables latentes se indica con valor del parámetro beta (β) y el p-valor de la prueba estadística de significancia. Obsérvese también que en cada una de las variables latentes dependientes se indica un valor de R^2 para medir la cantidad de varianza que es explicada por las variables dependientes.

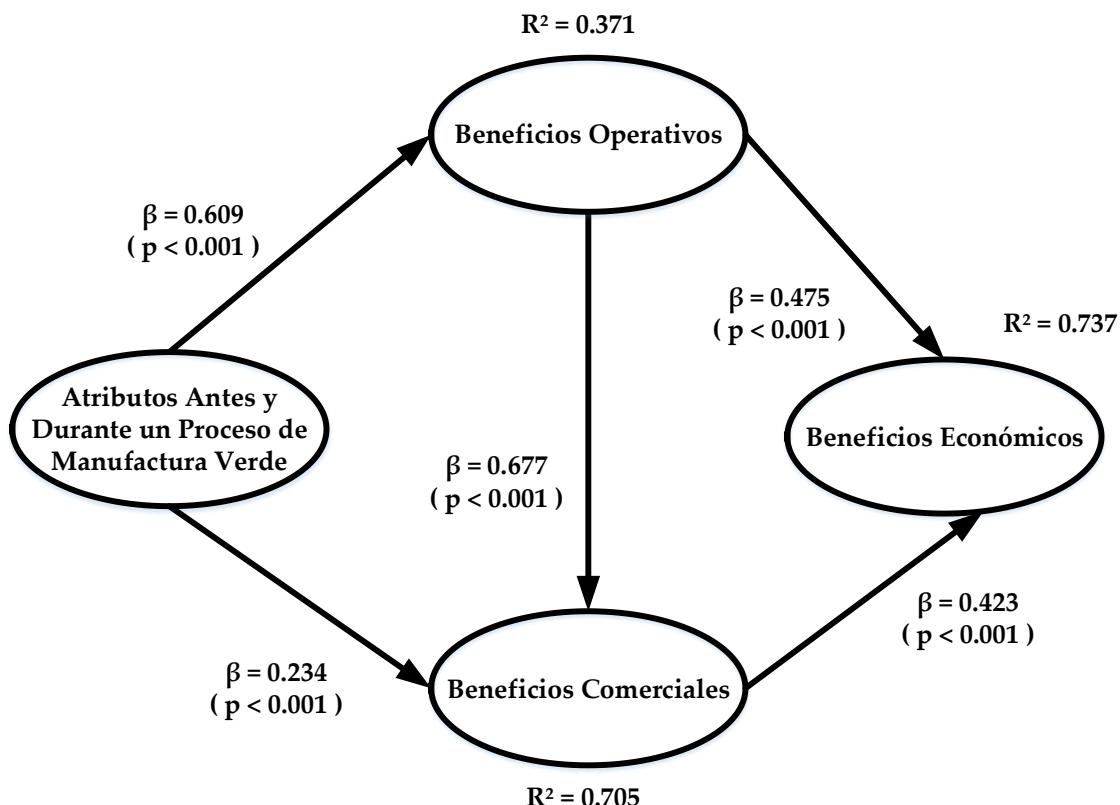


Figura 6. Modelo final.

Con la ejecución del modelo en el software se ha llegado a la validación o no de las hipótesis definidas y que a continuación se presentan:

- H_1 : Los *Atributos Antes y Durante un Proceso de Manufactura Verde* tiene un efecto directo y positivo en los *Beneficios Operativos* que se obtienen con la implementación de prácticas de MV.
- H_2 : Los *Atributos Antes y Durante un Proceso de Manufactura Verde* tiene un efecto directo y positivo en los *Beneficios Comerciales* que se obtienen al implementar prácticas de MV.

- H₃: Los *Beneficios Operativos* tiene un efecto directo y positivo en los *Beneficios Comerciales* que se obtienen al implementar prácticas de MV en las líneas de producción.
- H₄: Los *Beneficios Operativos* tiene un efecto directo y positivo en los *Beneficios Económicos* que obtienen con la implementación de un proceso de MV.
- H₅: Los *Beneficios Comerciales* tiene un efecto directo y positivo en los *Beneficios Económicos* que se obtienen con la implementación de un proceso de MV.

El modelo cuenta con diferentes tipos de efectos los cuales se presentan en la tabla 3.

Tipo de Efecto	Desde	Hacia	
Indirecto	Atributos Antes y Durante un Proceso de Manufactura Verde	Beneficios Comerciales	0.413 (P < 0.001) ES = 0.265
	Atributos Antes y Durante un Proceso de Manufactura Verde	Beneficios Económicos	0.563 (P < 0.001) ES = 0.310
	Beneficios Operativos	Beneficios Económicos	0.286 (P < 0.001) ES = 0.236
Total	Atributos Antes y Durante un Proceso de Manufactura Verde	Beneficios Operativos	0.609 (P < 0.001) ES = 0.371
	Atributos Antes y Durante un Proceso de Manufactura Verde	Beneficios Comerciales	0.647 (P < 0.001) ES = 0.416
	Atributos Antes y Durante un Proceso de Manufactura Verde	Beneficios Económicos	0.563 (P < 0.001) ES = 0.310
	Beneficios Operativos	Beneficios Comerciales	0.677 (P < 0.001) ES = 0.555
	Beneficios Operativos	Beneficios Económicos	0.761 (P < 0.001) ES = 0.628
	Beneficios Comerciales	Beneficios Económicos	0.423 (P < 0.001) ES = 0.345

Tabla 3. Efectos del modelo.

Con base a los resultados encontrados en el análisis de fiabilidad, se pueden tener las siguientes aportaciones teóricas:

- La implementación de la MV es un proceso continuo que debe ser monitoreado a lo largo de todo el sistema productivo, considerando que existen atributos que deben ser evaluados antes y durante el proceso de producción.
- La ejecución de actividades que propicien los *Atributos Antes y Durante un Proceso de Manufactura Verde* favorecen la obtención de *Beneficios Operativos*, ya que existe una probabilidad de que eso ocurra de un 0.485 y de *Beneficios Comerciales* con una probabilidad de 0.566.
- Los *Beneficios Operativos* en su nivel alto garantizan la obtención de *Beneficios Comerciales* altos (probabilidad de 0.586), por lo que los primeros deben ser una prioridad de los gerentes al implementar GM.

- Las empresas deben garantizar los *Beneficios Comerciales* en niveles altos para poder obtener *Beneficios Económicos* en ese mismo nivel (probabilidad de 0.510), ya que, si se tienen niveles bajos en la primera variable, se corre un alto riesgo de tener también bajos niveles en los *Beneficios Económicos* (probabilidad de 0.739).
- De lo anterior, se concluye que niveles altos en los *Beneficios Operativos* traen como consecuencia Beneficios Comerciales y éstos a su vez traen Beneficios Económicos.
- También se puede observar que no es posible tener *Beneficios Económicos* altos cuando se tienen *Beneficios Operativos* bajos, lo que indica nuevamente que los gerentes deben enfocarse en aspectos asociados al costo, calidad e imagen de la empresa.

4. CONCLUSIONES

En esta tesis se han presentado tres modelos de ecuaciones estructurales basado en mínimos cuadrados parciales. Y en base a los resultados obtenidos de los modelos aquí propuestos, las conclusiones son las siguientes:

- Los gerentes responsables en la selección y evaluación de proveedores tendrán que considerar usar tanto atributos tradicionales como atributos verdes, porque el uso de un solo tipo de atributos, no es suficiente para contar con un proceso productivo eficiente y garantizar un aprovisionamiento sustentable.
- Para que un proveedor sea competitivo, eficiente y eficaz en la entrega de materias primas, materiales y componentes deberá cumplir primeramente los atributos tradicionales como; la calidad, precio, tiempo de entrega y servicio postventa pues estos no han dejado de ser importantes ya que continúan primando sobre los atributos verdes.
- Es importante remarcar que integrar atributos tradicionales y verdes en la selección de un PV, garantizara la obtención de una serie de beneficios que se verán reflejados en los procesos productivos y comercialización en una determinada organización y la CSV de la misma.
- Por lo cual hoy en día no contar con un PV, es dejar de obtener una ventaja competitiva, comercial y económica y sobre todo no tener una responsabilidad social y ambiental.
- El uso de las TIC integradas y actualizadas es un ventaja importante para facilitar la implementación de una CSV, además de que las TIC ayudarán en la eficiencia, desempeño organizacional e igualmente constituir una fuente vital de competitividad para cualquier organización.
- Al utilizar las TIC integradas y actualizadas a lo largo de una CSV se crearán una serie de beneficios económicos, productivos y ambientales, además de minimizar el daño ecológico y la generación de un beneficio económico global.
- Se recomienda a las organizaciones invertir en el uso de las TIC al momento de llevar acabo la implementación de una CSV, ya que las TIC permitirán compartir información en tiempo real con los proveedores, los diferentes departamentos del sistema de producción y con los clientes, pero que, además, permitan dar cumplimiento a las normas y estándares establecidos por el país en el que se encuentran establecidas las empresas.
- El análisis de los resultados muestra que es posible obtener éxito para la empresa al implantar un proceso de MV, utilizando la clasificación de atributos antes y durante un proceso de MV.

- El uso de atributos de gran relevancia como herramienta para la evaluación o implementación de un proceso de MV, ya que contar con este tipo de procesos consigue mejorar el uso de los recursos, energía y materia prima y, por lo tanto, reducir el impacto ambiental.
- Se recomienda a las empresas que busquen transformar su proceso de manufactura tradicional a un proceso de MV, usen los atributos antes y durante un proceso de MV, pues estos atributos garantizan la obtención de una serie de beneficios, operativos, comerciales y económicos.
- Es importante recalcar que no contar con un proceso de MV puede situar a una empresa en una situación de desventaja, clasificándola como obsoleta. La MV es una herramienta trascendental para aprovechar, utilizar y concientizar al consumidor, clientes, proveedores y fabricante debido al impacto ambiental negativo que en estos momentos generan los proceso y productos que no son amigables con el medio ambiente o en sí que no son verdes.
- Finalmente se recomienda a las organizaciones que buscan transformar su CS tradicional a una CSV contar con un PV, usar las TIC como herramienta para facilitar las actividades trascendentales a lo largo de una CSV. además de que implementar un proceso de MV permite desarrollar productos y procesos verdes, con políticas de gestión ambiental proactiva y prácticas ambientales sanas, lo que les garantiza nuevos mercados verdes con clientes más comprometidos con su entorno y la conservación de este.

5. CONCLUSIONS

In this thesis three structural equations models based on partial least squares have been presented. In accordance with the obtained results from the proposed models, the conclusions are:

- Managers responsible for selection and evaluation of suppliers will have to consider using both traditional attributes and green attributes, since the use of only one type of attributes is not enough to have an efficient production process and guarantee a sustainable supply.
- In order for a supplier to be competitive, efficient and effective in the delivery of raw materials, materials and components, traditional attributes such as; the quality, price, delivery time and after-sales service because these have not stopped being important since they continue to prevail over the green attributes.
- It is important to note that integrating traditional and green attributes in the selection of a GSC, will guarantee obtaining a series of benefits that will be reflected in the production processes and marketing in a specific organization and its GSC.
- Therefore, today, not having a GSC, is practically no longer obtaining a competitive, commercial and economic advantage and above all not having a social and environmental responsibility.
- The use of integrated and updated ICT is an important advantage to facilitate the implementation of a GSC, in addition the ICT will help in efficiency, organizational performance and constitute a vital source of competitiveness for any organization.
- By using ICT integrated and updated throughout GSC, a series of economic, productive and environmental benefits will be created, besides generating a global economic benefit and minimizing the ecological damage.
- It is recommended that organizations invest in the use of ICT when carrying out the implementation of a GSC, since ICT will allow sharing information in real time with suppliers, the different departments of the production system and customers, but also, allow to fulfill with the norms and standards of the country in which the companies are established.
- The analysis of the results shows that it is possible to obtain favorable outcomes for the company when implementing an GM process, using the classification of attributes before and during a process of GM.
- Using highly relevant attributes as a tool for evaluation or implementation of an GM process, since having this type of processes manages to improve the use of

resources, energy and raw materials and, therefore, reduce the environmental impact.

- It is recommended to companies that seek to transform their traditional manufacturing process to an GM process, to use the attributes before and during an GM process, inasmuch as these attributes guarantee obtaining a series of operational, commercial and economic benefits.
- It is important to emphasize that not having an GM process can place a company at a disadvantage, classifying it as obsolete. The GM is a transcendental tool to take advantage of, use and raise awareness among consumers, customers, suppliers and manufacturers due to the negative environmental impact generated by the process and products that are not environmentally friendly or are not green.
- Finally, it is recommended to organizations that seek to transform their traditional supply chain to a GSC have a GS, use ICT as a tool to facilitate transcendental activities throughout a GSC. Besides implementing a GM process allows the development of green products and processes, with proactive environmental management policies and healthy environmental practices, which guarantees them new green markets with customers that are more committed to their environment and its conservation.

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7. PUBLICACIONES

Debido a que esta tesis se ha realizado por compendio de publicaciones en revistas científicas, todas ellas indexadas en el Journal Citation Reports (JCR).

Se exponen un análisis de cada una de las publicaciones puntuizando la revista en la que se ha publicado y algunos datos importantes de esta.

7.1 THE ROLE OF GREEN AND TRADITIONAL SUPPLIER ATTRIBUTES ON BUSINESS PERFORMANCE.

Este artículo fue publicado el día 26 de agosto de 2017 y a continuación se muestran algunos datos puntuales de dicho artículo:

- Fue publicado en la revista llamada "Sustainability" con ISSN 2071-1050 y de la editorial MDPI AG, Basel, Switzerland.
- Índice de impacto en Journal Citation Report 2017: 2.075
- Cuartil: Q2
- Categoría: Open access journal of environmental studies: green & sustainable science & technology.
- El artículo puede consultarse en <https://doi.org/10.3390/su9091520>.

7.2 ROLE OF INFORMATION AND COMMUNICATION TECHNOLOGY IN GREEN SUPPLY CHAIN IMPLEMENTATION AND COMPANIES' PERFORMANCE.

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8. ANEXOS

ARTÍCULO:

**THE ROLE OF GREEN AND TRADITIONAL SUPPLIER
ATTRIBUTES ON BUSINESS PERFORMANCE.**

Article

The Role of Green and Traditional Supplier Attributes on Business Performance

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Abstract: Supplier evaluation and selection are fundamental tasks since they are part of the production process and even initiate the supply chain (SC). Despite their importance in the production system, supplier evaluation and selection may be challenging activities to be performed if companies look at the wide range of available evaluation techniques and methodologies, which now seek to integrate both traditional and green attributes. In addition, companies may refuse to take into account green attributes during the supplier selection process, because they do not know their impact on commercial benefits. To overcome this limitation, this study examines the Mexican manufacturing sector and measures the impact of supplier traditional attributes and green attributes on business performance, namely production process benefits and commercial benefits. As data collection instrument, we administered a survey to 253 supplier evaluators and selectors; then, using the gathered data, we constructed a structural equation model. The model includes four variables to determine the impact of traditional and green attributes on business performance: green attributes, traditional attributes, production process benefits, and commercial benefits. The results indicate that all the latent variables have positive direct effects on one another. For instance, process benefits show the largest effects on commercial benefits, but the most significant effect is caused by traditional attributes on commercial benefits through green attributes and production process benefits.

Keywords: traditional attributes; structural equations model; supplier selection; commercial benefits and green attributes

1. Introduction

Supplier selection is a key to the successful development of a supply chain (SC) [1] and promotes effective buyer–supplier collaboration. To ensure this effective partnership and guarantee appropriate integration levels, companies pay careful attention to the vendors they select [2]. In addition, growing public awareness of environmental issues has favored the incorporation of green and socially responsible practices in the SC [3]. In other words, to improve their interaction with the ecosystems and reduce their ecological footprint, companies implement sustainable strategies in diverse SC activities, including materials procurement, production, consumption, and services, among others [4].

As a response to public environmental concerns and the growing use of sustainable practices along SCs, the concept of green supply chain management (GSCM) emerged as a philosophy to help

organizations reduce their ecological footprint and increase environmental efficiency without failing to obtain the desired business benefits [5,6]. GSCM has had a significant and positive impact on companies as it allows compliance with government regulations. It contributes to a greener corporate image and improves performance, which in turn helps to reap benefits that can later translate into greater financial or economic benefits [7–9]. Companies integrating greening in their supply chain differs from others that originally concentrated their efforts exclusively on operational and economic aspects and neglected the social and environmental implications of their operations [10]. In addition, GSCM is a competitive advantage for companies [11] and thus improves the SC [12].

The supplier selection process involves a series of activities, such as supplier identification, analysis, evaluation, and selection [13]. Since the 1960s, research has strived to identify the key supplier attributes; however, for a long time, vendors were traditionally evaluated under financial measures only [3]. In recent years, the rising popularity of green practices has encouraged companies to complement traditional supplier selection criteria, such as quality, delivery times, and costs, with green attributes. Environmental concerns have become public concerns, and thus environmentally-friendly practices have turned into strategic measures to select potential vendors [13]. For this reason, a successful SC is closely related to correct supplier selection [14].

The primary goal of this research is to help manufacturing industries improve their supplier evaluation and selection processes. In addition, with this work, we seek to quantitatively measure the relationships among green supplier attributes, traditional supplier attributes, production process benefits, and commercial benefits. In this sense, previous research works have found that considering supplier attributes has a positive impact on production process benefits [15], but the impact from those green attributes on benefits is not measured and this is the main contribution in this paper. Therefore, the second goal of this research is to determine if the consideration of both types of attributes, traditional and green, leads to the achievement of some benefit in production process or commercial, as well as quantitatively determine the positive impacts that exist between the four variables, given a dependence measurement.

1.1. Supplier Evaluation Techniques

Supplier selection refers to choosing the best supplier from a set to acquire the necessary materials to support the outputs of a company. Supplier selection can be a challenging process, since it is affected by a broad range of factors, both predictable and unpredictable. Moreover, suppliers can be very different from one another [16]. For such reasons, some studies argue that companies must take into account two elements for supplier selection and evaluation: the selection and evaluation criteria and the selection and evaluation method [17]. In order to evaluate a supplier, companies can employ distinct methods [18] and integrate a wide range of attributes related to costs, quality, delivery times, social responsibility, green certifications, and reliability, among others. Unfortunately, some of these attributes can be in conflict with one another [19]. Among the most common approaches to evaluating suppliers, we find immersive analysis, interpretive structural modeling, multi-attribute deterministic modeling, mathematical programming, analytic hierarchy process (AHP), fuzzy goal programming, TOPSIS (Technique for Order-Preference by Similarity to Ideal Solution), and VIKOR (the Serbian name is “VIšekriterijumsko Kompromisno Rangiranje” which means multi-criteria optimization and compromise solution) [20,21]. In addition, companies tend to monitor supplier development to identify, measure, and improve their performance and support the continuous improvement of the total value of goods and services within the SC. However, studies have concluded that AHP, fuzzy goal programming, and mathematical programming stand out as the most popular supplier selection methods [22].

1.2. Traditional Attributes for Supplier Selection

Since the 1960s, research on supplier selection has emphasized on attributes such as quality [23,24], delivery times [25], performance history [26], and costs [27]. Then, recent works analyzed the role of

these criteria under modern industrial environments and concluded that supplier selection nowadays relies more on such indicators as supplier technological capability [28], after-sales service [11,29], e-commerce [30], and quality and costs in a global market [31]. Such findings reveal that, although supplier selection has traditionally based on financial and service-related measures, recent concerns regarding the environmental and social implications of industrial activities have promoted the incorporation of both green and social attributes into traditional supplier evaluation methods [32].

1.3. Green Attributes in Supplier Selection

Recent literature and major trends in environmental management motivate the scientific community to research on the inclusion of environmental, social, and economic attributes into the supplier selection process [33,34]. This new sustainable approach to supplier selection became a trend as a result of customer demands, growing public concerns regarding environmental protection, and legal regulations. All these factors contribute to the view of sustainability as a business challenge and a competitive advantage [35,36] requested by both the government and private institutions [37,38].

There is a large variety of green attributes to be considered in supplier selection. Although it is difficult to rank their importance, and each company utilizes those that suit them best, some of the most common attributes include green certification [39], green image [40], green design [41], social responsibility [26,29], clean production [24], and green manufacturing [42]. Many experts agree that such criteria play a crucial role in the supplier selection process under a green approach, yet research has failed to systematize, categorize, and detail a contextual framework for supplier selection that combines both environmental and traditional supplier attributes [43]. As a result, traditional attributes remain at the core of supplier evaluation. However, when green or environmental attributes are integrated into the supplier selection process, many more evaluation criteria are required, especially to fulfill governmental and social regulations [34]. For this reason, we construct the first working hypothesis of our study as follows:

H_1 : In the manufacturing industry, *Traditional Supplier Attributes* have a positive direct effect on *Green Supplier Attributes*.

1.4. Production Process Benefits from Supplier Selection

Companies that select and evaluate suppliers through traditional criteria such as costs, quality, delivery times, and just in time (JIT) [44], among others, look for continuous improvement in processes and products to face competition. Moreover, vendors assessed by traditional attributes help companies reach performance objectives by operating effectively and efficiently [15,45]. In addition, the modern manufacturing industry seeks to reduce costs of raw materials, increase production efficiency, and reduce expenses [46,47]. In this sense, manufacturing companies can be sure that their production process, products, and SCs will succeed as long as the suppliers selected using traditional attributes are actively involved in the different production process stages [15]. In addition, the use of high-quality raw materials brings manufacturers numerous benefits, including waste, defect and rework reduction. Such benefits in turn help an organization to make profits and improve process efficiency [48]. Following this discussion, we propose the second working hypothesis of our study as follows:

H_2 : In the manufacturing industry, *Traditional Supplier Attributes* have a positive direct effect on *Production Process Benefits*.

Due to government regulations, customer exigencies, competitors, and the increasing popularity of environmental management, traditional supplier attributes are insufficient when choosing the best supplier. Nowadays, modern production systems ask companies and vendors to be actively involved in more environmentally-friendly practices, including green and clean production [31,45], end-of-life processing (recycling), and full compliance with local environmental regulations [49]. In addition, manufacturers are encouraged to increase supplier capability to modify the design and production processes and thus reduce their environmental impact [44,50]. All the supplier green attributes contribute to a less polluting production process and a cheaper recycling process. Moreover,

they are a means to avoid legal environmental sanctions [47,50]. Thus, considering the impact of green attributes on business performance, namely the production process, we propose the third working hypothesis of our research as follows:

H₃: In the manufacturing industry, *Green Supplier Attributes* have a positive direct effect on *Production Process Benefits*.

1.5. Commercial Benefits Gained from Supplier Selection

Some manufacturing companies still evaluate suppliers exclusively through financial-related attributes (e.g., quality and costs), yet this approach may not be completely effective by itself [51]. As mentioned earlier, suppliers must also be evaluated under other criteria, such as delivery times and after-sales service, especially to solve complaints and respond to warrants [52]. For instance, if a vendor fails to deliver raw materials on time, the production process may be abruptly interrupted, and timely product deliveries can be compromised [51]. This problem usually arises when manufacturing systems urgently require materials, but the supplying company is incapable of providing them when requested. Therefore, to avoid any potential harm to the manufacturer's production system, suppliers must comply with a wide range of standards. Such standards must be measured through correct attributes if companies wish to gain the expected benefits (e.g., improved corporate image, economic profits, and market expansion) [53]. Following this discussion, we propose the fourth working hypothesis of our study below:

H₄: In the manufacturing industry, *Traditional Supplier Attributes* have a positive direct effect on *Commercial Benefits*.

Current trends in environmental protection force manufacturing systems to go beyond traditional supplier selection methods to incorporate green attributes into a more holistic evaluation approach [31]. Three of the most common green supplier attributes are green certifications, green practices, and compliance with required environmental regulations [39]. A more sustainable approach to supplier selection contributes to projecting a green corporate image for customers and SC partners [24,40]. In addition, manufacturing companies that evaluate suppliers through green attributes can take advantage of the benefits of their environmental management practices in their production processes, which are geared toward generating new environmentally-friendly products [54]. Similarly, manufacturers would enjoy the new green image they have fostered, benefit from noticeably market expansion, and promote a sociably responsible culture among SC partners, thereby constructing a solid, green SC [4]. Taking into account the impact of green attributes on commercial benefits, we construct the fifth working hypothesis of our study below:

H₅: In the manufacturing industry, *Green Supplier Attributes* have a positive direct effect on *Commercial Benefits*.

The production process benefits obtained from green supplier selection can be easily transformed into commercial benefits. When manufacturing companies produce high-quality and environmentally-friendly products, they automatically improve their corporate image, expand market, and increase their gains [41,55]. As an example, manufacturing companies that use timely delivered, low-cost, and high-quality raw materials are acknowledged by customers, guarantee timely product deliveries, and stand as reliable enterprises [2,56]. Additionally, if manufacturers work on building a green image, they can successfully stand as socially responsible organizations as well. Therefore, considering the impact of production process benefits as a result of appropriate supplier selection over commercial benefits, we propose the last working hypothesis of our research as follows:

H₆: In the manufacturing industry, the *Production Process Benefits* obtained from supplier selection have a positive direct effect on *Commercial Benefits*.

2. Methodology

To provide a comprehensive report of the research approach adopted in this study, we divided this section into five main stages, thoroughly explained in the following paragraphs.

2.1. Stage 1. Questionnaire Design and Administration

To know the importance of green and traditional supplier attributes to manufacturing companies and identify the impact of such attributes on commercial and production process benefits, we interviewed workers directly involved in the supplier selection process. To collect the necessary data, we designed and administered a questionnaire. To design the questionnaire, we conducted a literature review in different databases and searched for information related to the most commonly assessed green and traditional supplier attributes and their reported benefits. This literature review was the rational validation of the questionnaire.

The questionnaire was composed of three sections. The first section included an introduction paragraph describing the research goal and the purpose of the survey. In addition, the section included sociodemographic questions regarding age, genre, job position, years of work experience, company size, and manufacturing sectors. On the other hand, the second section of the questionnaire included 18 questions to assess 18 supplier attributes—green and traditional. As mentioned earlier, such attributes were identified in the literature review and are listed in Table 1. The questions regarding these attributes were answered using a five-point Likert scale, whose lowest value (1) indicated that an attribute was not at all important to a company during the supplier selection process, whereas the highest value (5) implied that the attribute was highly important. Finally, the third section of the questionnaire was composed of 11 questions that analyzed the commercial and production process benefits obtained from supplier selection. For this part of the questionnaire, we took the survey developed by [57] as a guide. As in the second section of the questionnaire, questions in this section were answered using a five-point Likert scale.

To differentiate the concepts and latent variables here analyzed, the traditional attributes in a supplier are those that serve to evaluate the performance, quality and the cost, on the process and product [24,40]. However, green attributes evaluate the environmental business practices, impacts of business operations associated to environment, environmental management and environmental performance [6,39]. The production process benefits serve companies to meet the performance objectives in production lines, increase efficiency and effectiveness as the quality of the products, delivery time and waste reduction [15,47]. In addition, the commercial benefits serve the companies to improve the corporate image, expand their markets and increase economic earnings [41,53]. Table 1 illustrates the list of items for every latent variable and some references justifying its integration.

Table 1. Attributes and Benefits.

Traditional Attributes	Green Attributes
Economic Stability [15,58]	Green Image [4,40] Green Manufacturing [42,59]
Production Process Flexibility [40,55]	Green Design [7,41]
Just in Time (JIT) Implementation [29,44]	Recycling System [31,49]
Product Cost [31,55]	Green Certification [39,60]
Business Experience [11,30]	Environmental Costs [38,44]
Previous Contracts [38,55]	Control of Pollutant Emissions [40,61]
Employee Capacity Building [15,58]	Social Responsibility [26,29]
Problem Solving Capacity [29,49]	Clean Production [24,31] Green Process Management [4,58,61]
Production Process Benefits	Commercial Benefits
Decreased Quality Problems [40,62]	Market Expansion to Local Areas [15,42]
Waste Minimization [2,26]	Green Corporate Image [20,63]
Shorter Delivery Times [2,15]	Market Expansion to National Areas [15,26]
Decreased Customer Complaints [41,65]	Increased Economic Earnings [41,64] Economic Earnings [41,66] Supply Chain Improvements [58,65]

Since the attributes assessed in the questionnaire were gathered from research works conducted in other countries, we submitted the final version of our instrument to an expert validation. For this validation, the panel of experts was composed of five specialists—three manufacturing industry experts and two academics—who reviewed the content of the questionnaire and assessed whether it was appropriately adapted to the research context. Then, the final version of the questionnaire was administered to company managers and supplier selectors and evaluators with more than two years of experience.

2.2. Stage 2. Database Creation and Screening

The gathered data were captured in a database designed using SPSS 21® statistical software. Before analyzing data, we performed a screening process to detect missing values and outliers. Missing data occur when participants do not know the answer to a question, or they simply do not want to answer it. We discarded questionnaires showing more than 10% of missing values, but we retained those having less than 10% [67]. In such cases, we replaced the missing values with the median value of items, since we collected ordinal data [68].

To detect outliers, we constructed box-and-whisker plots. Outliers lie close to the whiskers of a diagram, since they represent the extreme of data. Then, we standardized the data, considering any value above four as an outlier [69]. Finally, we estimated the standard deviation value of each questionnaire. Standard deviation values close 0 indicated that the respondent had assigned the same value to all the items. In addition, a standard deviation value below 0.5 on a Likert-scale confirmed that the involved questionnaire had to be removed from the analysis [70].

2.3. Stage 3. Statistical Validation

Seven indicators were used to validate the data. The Cronbach's alpha index helped us measure reliability in the scale, only accepting values above 0.7, whereas the composite reliability index was used for measuring the internal validity of the data. In other words, we used the composite reliability index to define whether the items were highly correlated among them and thus belonged to a same latent variable. Likewise, we computed the Average Variance Extracted (AVE) as a measure of convergent validity, always looking for values above 0.5. Coefficients R-Squared, Adjusted R-Squared, and Q-squared were employed to measure the predictive validity of data. The former two are coefficients of parametric predictive validity, and the third one is a coefficient of nonparametric predictive validity [71]. Finally, Full collinearity VIF allowed us to detect both lateral and vertical collinearity in latent variables. Although some studies accept values below 5, we accepted values lower than 3.3.

2.4. Stage 4. Descriptive Analysis

At this stage, we conducted a descriptive analysis of both the sample and the questionnaire items. Both analyses are thoroughly described in the following subsections.

2.4.1. Descriptive Analysis of the Sample

The sociodemographic data gathered in the first section of the questionnaire allowed us to characterize the sample based on particular characteristics, thus identifying age, genre, current job position, years of work experience, company size, and surveyed industries. Additionally, we constructed contingency tables to detect trends between two variables.

2.4.2. Descriptive Analysis of Items

We performed a descriptive analysis of the questionnaire items in every latent variable. We computed the median as a measure of central tendency and the interquartile range (IQR) as a measure of data dispersion, also estimating both the first and third quartile of data. Any high median value indicated that an attribute is important to supplier selection and evaluation or a given benefit is

always obtained from supplier selection and evaluation. On the other hand, a low median value in an item indicated that an attribute is not important to supplier selection and evaluation or a given benefit is never obtained from supplier selection and evaluation. Finally, as for the IQR, high values indicated indicated low consensus among the respondents regarding the median value of an item, while low low consensus among the respondents regarding the median value of an item, while low IQR values IQR values indicated high consensus among the participants [72].

2.5. Stage 5: Structural Equations Modelling

To prove the hypotheses stated in Figure 1, we constructed a model and evaluated it using Structural Equations Modeling (SEM). SEM is a popular technique employed to study and validate causal relationships in supply chain environments, including supplier selection and JIT implementation. In this research, we executed the structural equation model in WarpPLS 5.0® software, whose main algorithms are based on Partial Least Squares (PLS), widely recommended for small-sized samples [73]. More specifically, our model was executed with WarpPLS 5.0 PLS algorithm with a bootstrapping resampling method to assign a measure of accuracy to sample estimates and diminish the effects of possible outliers.

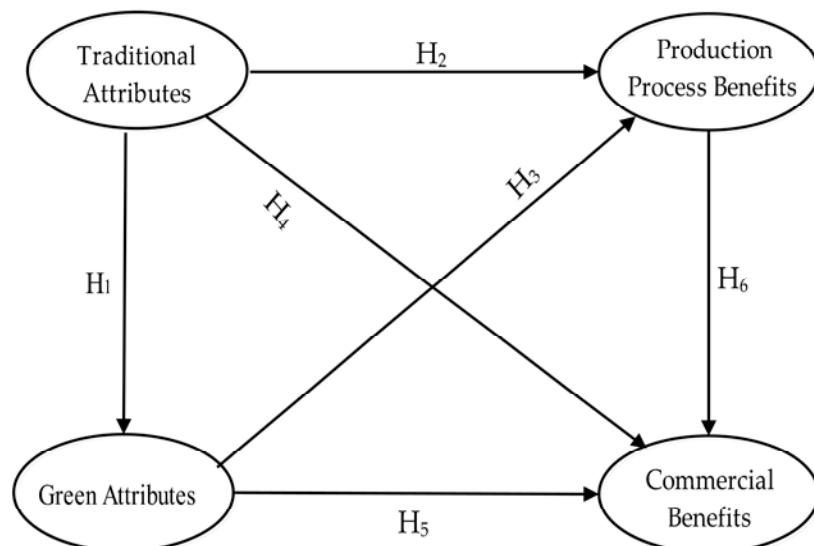


Figure 1. Research hypotheses.

To test the model, we estimated six model fit indices: Average Path Coefficient (APC), Average R-Squared (ARS), Average Adjusted R-Squared (AARS), Average Variance Inflation Factor (AVIF), Average Full collinearity VIF (AFVIF), and the Tenenhaus Goodness of Fit (GoF) index. For APC, ARS, and AARS, we estimated the p -values to test the efficiency of the model, setting 0.05 as the maximum acceptable value. This allowed us to obtain inferences statistically significant at a 95% confidence level, thereby testing the null hypotheses $APC = 0$; $ARS = 0$ against the alternative hypotheses: $APC \neq 0$; $ARS \neq 0$.

As regards AVIF and AFVIF, we exclusively accepted values equal to or lower than 3.3. This threshold is particularly applicable for models in which most of the variables are measured using two or more indicators. In addition, to estimate the model's explanatory power, we computed the Tenenhaus GoF index, accepting values ranging from 0.1 to 0.36 [73]. In general, GoF values equal to or greater than 0.6 suggest that a model has small explanatory power, whereas values equal to 0.25 or greater than 0.25 indicate medium explanatory power. Finally, GoF values equal to 0.36 or greater than 0.36 denote large explanatory power.

In addition to estimating the six model fit indices, we analyzed our structural equation model by measuring three types of effects between latent variables: direct, indirect, and total effects. Direct effects can be noted in Figure 1 as arrows directly connecting two latent variables, whereas indirect effects occur through a third latent variable using two or more paths or segments. The total effects between two latent variables are the sum of both direct and indirect effects. All the effects were associated with a p -value to determine their significance, thus considering the null hypothesis: $\beta_i = 0$, versus the alternative hypothesis: $\beta_i \neq 0$.

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3. Results

The results from the model analysis and evaluation are reported in the following four subsections.

3.1. Latent Variables Validation

Table 2 shows the results from the validation test performed on the latent variables depicted in Figure 1. The values above 0.2 in R-Squared, Adjusted R-squared, and Q-Squared, seen in the three dependent latent variables, demonstrated that the model has appropriate predictive validity from both parametric and non-parametric perspectives. Likewise, we obtained values above 0.7 for the Cronbach's alpha and the composite reliability index, which confirmed that all the latent variables had internal validity. As for AVE and Full collinearity VIF indices, we concluded that every latent variable had acceptable convergent validity and no collinearity problems, since the AVE values were above 0.5, and the Full collinearity VIF values were lower than 3.3.

Table 2. Latent Variable Coefficients.

Latent Variable Coefficients	Traditional Attributes	Green Attributes	Production Process Benefits	Commercial Benefits
R-Squared		0.442	0.279	0.746
Adj. R-Squared		0.440	0.273	0.743
Q-Squared		0.443	0.281	0.690
Composite reliability	0.864	0.941	0.914	0.939
Cronbach's alpha	0.820	0.930	0.874	0.922
AVE	0.544	0.616	0.727	0.720
Full collinearity VIF	1.839	2.320	2.911	3.238

3.2. Descriptive Analysis of the Sample

After three months of survey administration, we collected 270 questionnaires. Only 253 of them were analyzed, since the remaining 27 were invalidated during the data screening process. The results from the sample's descriptive analysis indicated that 51.77% of surveyed workers serve in departments directly interacting with suppliers, such as the logistics, materials, procurement, and management departments. Meanwhile, the remaining 48.23% of employees work in the engineering, manufacturing, or methods engineering departments. Similarly, we found that 50.19% of the sample works in the automobile sector or the medical sector, the two most prominent industries in Mexico.

3.3. Descriptive Analysis of Items

Table 3 introduces the results from the descriptive analysis performed on the items. As for Traditional Attributes, seven items reported a median value above 4, while only one showed a lower median value. On the other hand, in Green Attributes, only item Green Certification showed a median value higher than 4. Finally, none of the 11 items assessing Production Process Benefits and Commercial Benefits showed a median value higher than 4, which confirms that these types of benefits are regularly obtained in Mexican manufacturing companies.

As regards the statistical dispersion of data, items Green Production process and Green Design reported the highest IQR values among all the items contained in both Green Attributes and Traditional Attributes. Such results denote low consensus among respondents regarding the importance of the

two attributes. However, item JIT Implementation showed the lowest IQR, which suggested high consensus among respondents on the role of this attribute in the supplier selection process. Finally, for Production Process Benefits and Commercial Benefits, the results demonstrated low consensus among employees as regards the extent to which Decreased Customer Complaints is a benefit regularly obtained from supplier selection. On the other hand, consensus among respondents for benefit Market Expansion to Local Areas seems to be greater, since the item reported the lowest IQR.

Table 3. Descriptive analysis of items.

Items	Median	IQR
Traditional Attributes		
Economic Stability	4.180	1.501
Just in Time (JIT) Implementation	4.426	1.289
Product Cost	4.277	1.414
Business Experience	4.188	1.493
Production Process Flexibility	4.028	1.541
Previous Contracts	3.245	1.683
Employee Capacity Building	4.034	1.502
Problem-Solving Capacity	4.160	1.493
Green Attributes		
Green Image	3.561	1.803
Green Manufacturing	3.525	1.786
Green Design	3.473	1.870
Recycling System	3.803	1.830
Green Certification	4.119	1.698
Environmental Costs	3.796	1.735
Control of Pollutant Emissions	3.786	1.766
Social Responsibility	3.910	1.582
Clean Production	3.987	1.582
Green Process Management	3.613	1.950
Production Process Benefits		
Decreased Quality Problems	3.052	1.849
Waste Minimization	2.833	1.853
Shorter Delivery Times	3.051	1.873
Decreased Customer Complaints	2.674	1.890
Commercial Benefits		
Market Expansion to Local Areas	2.452	1.620
Corporate Image	2.642	1.798
Market Expansion to National Areas	2.468	1.824
Increased Economic Earnings	2.727	1.772
Economic Earnings	2.695	1.810
Supply Chain Improvements	2.649	1.826

3.4. Structural Equations Model

The structural equation model constructed for this research was tested according to the methodology described in earlier sections. The results of this evaluation are depicted in Figure 2. Note that every segment of the figure graphically represents the relationship between two latent variables and includes a β -value and a p -value for the statistical testing of the hypotheses. In addition, every dependent latent variable is associated with an R^2 value as a measure of explained variance.

The model fit indices obtained for the structural equation model are listed below:

- Average path coefficient (APC) = 0.378, $p < 0.001$
- Average R-squared (ARS) = 0.489, $p < 0.001$
- Average adjusted R-squared (AARS) = 0.485, $p < 0.001$

- Average block VIF (AVIF) = 1.733, acceptable if ≤ 5 , ideally ≤ 3.3
- Average full collinearity VIF (AFVIF) = 2.577, acceptable if ≤ 5 , ideally ≤ 3.3
- Tenenhaus GoF (GoF) = 0.554, small ≥ 0.1 , medium ≥ 0.25 , large ≥ 0.36

The results from the model's fit and quality evaluation suggest that the model was appropriate and could be interpreted accordingly. On the one hand, the p -values of APC, ARS, and AARS allowed us to conclude that the model possessed enough predictive validity, and the dependencies between the latent variables, on average, were different from 0, since they were statistically significant at a 95% confidence level. On the other hand, we discarded collinearity problems in the model, since AVIF and AFVIF values were lower than 3. Finally, the value of the Tenenhaus GoF index suggested acceptable fit of the model to the data.

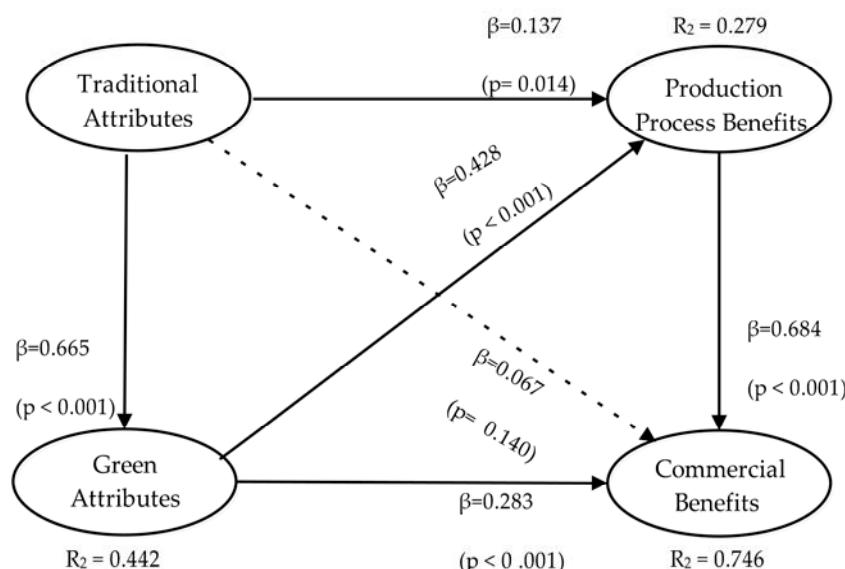


Figure 2. Evaluated model.
Figure 2. Evaluated model.

3.5. Direct Effects

Direct effects are used to analyze the hypotheses stated early in the study and depicted in Figure 1. As previously mentioned, the results from the model evaluation are shown in Figure 2, based on which we can provide the following conclusions for the model hypotheses or direct effects found between the latent variables.

H₁: There is enough statistical evidence to affirm that the Traditional Attributes considered in supplier selection have a positive direct effect on Green Attributes in the manufacturing industry, since, when the first latent variable increases its standard deviation by one unit, the standard deviation of the second latent variable increases by 0.665 units.

H₂: There is enough statistical evidence to affirm that the Traditional Attributes considered in supplier selection have a positive direct effect on Production Process Benefits in the manufacturing industry, since, when the first latent variable increases its standard deviation by one unit, the standard deviation of the second latent variable increases by 0.137 units.

H₃: There is enough statistical evidence to affirm that the Green Attributes considered in supplier selection have a positive direct effect on Production Process Benefits in the manufacturing industry, since, when the first latent variable increases its standard deviation by one unit, the standard deviation of the second latent variable increases by 0.428 units.

H₄: There is not enough statistical evidence to affirm that the Traditional Attributes considered in supplier selection have a positive direct effect on Commercial Benefits in the manufacturing industry, since, in this hypothesis, the p -value associated with the β parameter was higher than 0.05.

H₅: There is enough statistical evidence to affirm that the Green Attributes considered for supplier selection have a positive direct effect on Commercial Benefits in the manufacturing industry, since, when the first latent variable increases its standard deviation by one unit, the standard deviation of the second latent variable increases by 0.286 units.

H₆: There is enough statistical evidence to affirm that the Production Process Benefits gained

H_5 : There is enough statistical evidence to affirm that the Green Attributes considered for supplier selection have a positive direct effect on Commercial Benefits in the manufacturing industry, since, when the first latent variable increases its standard deviation by one unit, the standard deviation of the second latent variable increases by 0.286 units.

H_6 : There is enough statistical evidence to affirm that the Production Process Benefits gained from supplier selection have a positive direct effect on Commercial Benefits in the manufacturing industry, since, when the first latent variable increases its standard deviation by one unit, the standard deviation of the second latent variable increases by 0.684 units.

As for the dependent latent variables, the results depicted in Figure 2 show Commercial Benefits being 74.6% explained by latent variables Traditional Attributes (2.7%), Green Attributes (17.0%), and Production Process Benefits (54.9%), since $R^2 = 0.746$. Such results demonstrate that to gain Commercial Benefits, manufacturing companies must focus on those Production Process Benefits that can be gained from supplier selection. Table 4 summarizes the results from the hypotheses validation.

Table 4. Direct effects and hypotheses validation.

Hypothesis	VI	VD	β	p-Value	Decision
H_1	TA	GA	0.665	$p < 0.001$	Accepted
H_2	TA	PPB	0.137	$p = 0.014$	Accepted
H_3	GA	PPB	0.428	$p < 0.001$	Accepted
H_4	TA	CB	0.067	$p = 0.140 *$	Rejected
H_5	GA	CB	0.286	$p < 0.001$	Accepted
H_6	PPB	CB	0.684	$p < 0.001$	Accepted

TA =Traditional Attributes, GA = Green Attributes, PPB = Production Process Benefits, CM = Commercial Benefits.

* Hypothesis rejected under a 95% confidence level.

3.6. Sum of Indirect Effects

The model evaluated in Figure 2 shows four indirect effects listed as follows:

1. Latent variable Traditional Attributes has an indirect effect on Production Process Benefits through Green Attributes. This effect equals 0.284 units ($p < 0.001$), it is statistically significant at a 95% confidence level, and the former latent variable explains 11.9% of the variability of the latter, since the effect size (ES) equals 0.119 units.
2. The same latent variable, Traditional Attributes, also has an indirect effect on Commercial Benefits through Green Attributes and Production Process Benefits. In this case, the indirect effect equals 0.284 ($p < 0.001$), it is statistically significant at a 95% confidence level, and Traditional Attributes explain up to 11.4% of the variability of Commercial Benefits, since ES = 0.114.
3. Latent variable Traditional Attributes has an indirect effect on Commercial Benefits through Green Attributes. The effect equals 0.194 units ($p < 0.001$), it is statistically significant at a 95% confidence level and can be tracked following three segments. In addition, in this indirect effect, Traditional Attributes explain 7.8% of the variability of Commercial Benefits, since ES = 0.078.
4. Latent variable Green Attributes has an indirect effect on Commercial Benefits through Production Process Benefits. The effect equals 0.292 units ($p < 0.001$), it is statistically significant at a 95% confidence level, and can be tracked following two segments. In addition, in this effect, Green Attributes explain 17.4% of the variability of Commercial Benefits, since ES = 0.174.

Table 5 summarizes the indirect effects found after evaluating the model proposed in Figure 2.

Table 5. Sum of indirect effects.

To	From	
	Traditional Attributes	Green Attributes
Commercial Benefits	0.478 ($p < 0.001$) ES = 0.193	
Production Process Benefits	0.284 ($p < 0.001$) ES = 0.119	0.292 ($p < 0.001$) ES = 0.174

3.7. Total Effects

The sum of the direct and indirect effects between two latent variables is known as total effects. Table 6 presents the total effects found in the model. In three relationships, the direct effects equal the total effects, since no indirect effects were found. However, the remaining three relationships include both direct and indirect effects. In addition, notice the relationship between Traditional Attributes and Commercial Benefits, in which the direct effect was not statistically significant at a 95% confidence level, but the indirect effect occurring through Green Attributes and Commercial Benefits was significant. Such results suggest that even if suppliers meet the standards established in terms of raw materials delivery, they may not positively impact on the Commercial Benefits of manufacturers if these manufacturing companies have ineffective production processes. In other words, the production process is the means to successfully comply with customer demands, requested as product characteristics.

Table 6. Total effects.

To	From		
	Traditional Attributes	Green Attributes	Production Process Benefits
Green Attributes	0.665 ($p < 0.001$) ES = 0.442		
Commercial Benefits	0.545 ($p < 0.001$) ES = 0.220	0.579 ($p < 0.001$) ES = 0.343	0.684 ($p < 0.001$) ES = 0.549
Production Process Benefits	0.421 ($p < 0.001$) ES = 0.177	0.428 ($p < 0.001$) ES = 0.222	

4. Conclusions and Industrial Implications

By means of a structural equation model, we demonstrate in this research that relying on suppliers with competitive attributes is useless if such attributes cannot be converted into a competitive strategy during the production process. In addition, the fact that the fourth model hypothesis was rejected because Traditional Attributes alone have no significant effects on Commercial Benefits demonstrates that traditional supplier attributes are nowadays insufficient to evaluate providers. In other words, providers who are solely evaluated in terms of their compliance with timely deliveries, economic specifications, and experience, among others, do not represent a competitive advantage to manufacturing companies and fail to make profits. However, because Traditional Attributes have significant indirect effects on Commercial Benefits through Green Attributes and Production Processes Benefits, our model validates the importance of including both traditional and green supplier attributes in supplier selection and evaluation approaches. This strategy would contribute to more holistic supplier evaluations and will help companies obtain the desired benefits.

As regards the correlation between Traditional Attributes and Production Process Benefits, the fact that the indirect relationship between these variables—occurring through Green Attributes—is higher than their direct relationship proves that traditional supplier attributes alone cannot guarantee efficient production processes anymore. Such results highlight the importance of combining green

supplier attributes with traditional supplier attributes, as they complement each other. Moreover, Traditional Attributes have a large impact on Green Attributes. That is, our model demonstrates the prominent role of traditional supplier attributes in supplier evaluation and selection; however, it is important that manufacturers equally consider and integrate green supplier attributes in the supplier selection process to gain the expected production process benefits, and as consequence, the desired commercial benefits.

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Conflicts of Interest: The authors declare no conflict of interest.

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ARTÍCULO:

**ROLE OF INFORMATION AND COMMUNICATION
TECHNOLOGY IN GREEN SUPPLY CHAIN
IMPLEMENTATION AND COMPANIES' PERFORMANCE.**

Article

Role of Information and Communication Technology in Green Supply Chain Implementation and Companies' Performance

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Abstract: The aim of this study is to quantify the impact of information and communication technologies (ICT) and its technological updates on the success of the green supply chain (GSC) implementation, as well as the benefits this affords. This research is applied to the Mexican maquiladora export industry. A model of structural equations is presented to know the importance of the integration of ICT, combined with the implementation of GSC and the generation of benefits with the use of ICT. The results indicate that there is a direct, positive effect (PE) and significant among the four latent variables (LTV) analyzed but the most noteworthy is the indirect effect that the variable updating the ICT has on the benefits of GSC, through the variable mediators' implementation of a GSC, since the direct effect of updating the ICT on the benefits of the implementation of GSC does not become significant. Whereby, it is recommended that the industry integrates and updates its ICT since, using the integrated and updated ICT and the implementation of a GSC, a series of economic, productive and environmental benefits will be created.

Keywords: information and communication technologies; green supply chain; update and sustainable

1. Introduction

Nowadays, organizations must always ensure they consider their environmental impact. Not doing so makes them outsiders, as the concepts of environmental and social sustainability are becoming increasingly popular amongst organizations, providers, distributors and clients. Adopting a more respectful approach to the environment is now an obligation, not a choice [1]. Organizations develop diverse business strategies but the important and most widely-used is that of the green supply chain (GSC) [2]. GSCs allow a balance between ecological, financial and social benefits, as well as provide a solution to environmental problems and image generated by the different activities which make up the traditional supply chain (SC) [3].

A GSC is a coupling of environmental thinking and traditional SC management [4], which involves several phases in the life of a product: design, selection and material supply, manufacturing processes, integrating information communication technology (ICT), delivering the final product to the consumer and its evaluation at the end of its life-cycle [5,6]. That is, the GSC is the generation of green purchases, green manufacturing, green packaging, the adoption of green technology, green distribution and green marketing, what it is being looked for, trying to eliminate or minimize waste in the form of hazardous,

chemical, energy, emission and solid waste [6–8]. By adopting a GSC, companies improve their image and social acceptance and they generate higher financial income and so forth.

However, implementing a GSC is no easy task, because it requires a flexible, agile, robust and sustainable design, with long-term results for its procedures, products and green logistics systems [2]. To facilitate the GSC implementation process, companies are integrating ICT into their SC [9,10].

In this context, the use of ICT in the implementation of a GSC requires: the development of information systems, manufacturing which is service focused, intelligent products, robust product testing, environmental intelligence, optimization, energy awareness and auto-organized systems for environmental monitoring [11]. These technologies were inconceivable in the past but have currently helped to provide versatile solutions to the challenges faced in a GSC [12].

All the above shows a tendency towards ‘green’ supply chains and the implementation of ICT has been a great help in speeding up this process and in obtaining the benefits that that philosophy offers [13]. Therefore, the aim of this study is to quantify the effect ICT and its technological updates has on the success of the implementation of a GSC, as well as the benefits this affords. The results obtained from this research will allow the people responsible for SCs to identify the importance of ICT in the successful implementation of the GSC philosophy and its benefits. It will also make possible the identification of important aspects of those that are trivial in the functioning of GSCs.

2. Hypotheses and Literature Review

2.1. Integrating and Updating ICT in a GSC

ICTs are technologies which were originally meant to support the exchange of information but in modern-day life ICTs are playing an increasingly important role in our day to day life as humans [14]. Said activities include collating, processing, storing and exchanging information quickly and easily, as well as offering alternative methods in which to work, improving supply chains, controlling transport, energy supply and so forth [15]. In fact, these examples are widely used in predictions about our future, as there are more and more activities which involve more efficient communication and collaboration systems. ICTs have a role to play within the production process, financial management, the relationship with providers, clients and they are considered a vital source of competitiveness and innovation in sustainable industrial systems [12,16].

One of the main advantages offered by ICT in SCs is the exchange of information (EI) in real time and proper form, via the use of intelligent communication networks, such as internet, intranet, Enterprise Resource Planning (ERP), Customer Relationship Management (CRM) and others. Another benefit is that they are used by all members of the SC and can improve the efficiency and the number of eco-friendly practices as well as reduce costs and the need for inventories [11]. ICT has radically and efficiently transformed a great deal of production and transport processes. It allows for the virtualization of products, the digitalization of information, the de-materialization of transport and a reduction in storage space [17].

There are many studies which state that the EI increases the level of service and reduces the time involved in a GSC cycle. All of this affects general expenses, chain inventories, transport and storage costs [11]. It also makes it possible to improve the strategic order of the SC components, feedback and exchange of information in real-time with clients and providers. This means that predictions for demand and production planning are more real and precise.

Besides, the application of updating ICT of a high technological update is considered a powerful tool in the improvement of companies. It allows for an improvement in energy efficiency and EI in many financial sectors. ICT currently provides efficient technical support for environmental monitoring in real time, the management of natural resources and emissions evaluations. The way in which ICT is applied has evolved and makes it possible to reach the environmental objectives of a GSC, whilst also creating value for the market, as well as being a competitive advantage [18]. Not all ICTs have the same benefits however and it all depends on how up-to-date and innovative they are. The impact of ICT

is reflected in two ways: ecological product innovation (which provides clients with new ecological products) and innovation in ecological procedures (green production process) [19]. Having taken the above into consideration, we suggest the next hypothesis:

Hypothesis 1. (H₁) *The integration of ICT has a direct and positive effect on updating ICT within a GSC.*

2.2. The Implementation of GSC

A GSC is a network made up of providers, producers, storage facilities and distributors who work together to turn their plans, activities and raw material into a final product. This SC must also include an environmental outlook across all stages [20]. When it comes to implementing a GSC, the use of ICT is important to try and improve the sustainability of the company's communication, provisioning and transport systems, all of which allows for client and provider involvement (external part of the company's business). This coordination via ICT means that procedures, products and communication via the EI can be better integrated, whilst also minimizing the cost and environmental impact.

A successful implementation of ecological ICTs also contributes to the correct implementation of the GSC. Costs are reduced, relationships between members are improved, the flow of materials increases, deliveries are faster, client satisfaction improves and, what is most important, an environmentally-friendly outlook is reinforced across the entire SC [21]. By implementing the GSC, the use of a unified system and a centralized control system such as ICT, companies improve their inverse logistics with the design of ecological products and procedures. With the aim of determining whether the integration of ICTs facilitates the implementation of a GSC, we suggest the next hypothesis:

Hypothesis 2. (H₂) *The integration of ICT has a direct and positive effect on the implementation of GSC.*

By implementing a GSC, organizations can minimize and eliminate the negative effects that a SC has on the environment, as well as improve the company's technological or innovative standards. Similarly, ICT must have a positive impact on the environment and produce a PE on the design and processes of eco-products [5]. In order to innovate the GSC technologically the organization must invest in updating of ICT which is able to design products ecologically and monitor production and distribution systems [22], taking into account the fact that these could become obsolete in a very short period of time.

Investment in ICT is currently linked to business growth as well as to the growth of the world's economy [23]. There are specific cases that compare the benefits and productivity obtained by companies of different technological updates (with different levels of up-to-datedness) and those using recently created technologies show a clear advantage [24,25]. Considering that how up-to-date the ICT that an organization uses, as well as its technological updates, have a role to play in company operations and their SC, we suggest the next hypothesis:

Hypothesis 3. (H₃) *Updating of ICT has a direct and positive effect on the implementation of GSC.*

2.3. Benefits of the Implementation of GSC

In a GSC implementation, ICTs have been identified as one of the main forces when it comes to facilitating the process of obtaining social, economic and operative benefits [26]. Nevertheless, we must not forget that the aim of a GSC must be to subject all of an organizations' activities to strict environmental demands and technological innovations in its processes and products, with the objective of maximizing the growth of its income, investment and corporate image [21].

As above mentioned, one of ICT's most valuable resources is EI, as it facilitates a whole list of benefits. These include products which are better adjusted to consumer demand, a reduced need for inventories, the ability to anticipate market changes to reduce transport and increase sales, the ability to respond quickly and detect problems in their early stages to reduce any losses and so forth [24,27].

A successful EI shows three potential advantages for producers: a reduction in costs, a reduction in inventory and a reduction in their environmental impact [28]. Partners and participants in the implementation project can benefit from: changing their existing plans, formulating future operations, improving their efficiency, reducing transport, reducing environmental costs and improving their customer service. Having taken the above into consideration, the following hypothesis is proposed:

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Hypothesis 4. (H_4) *The integration of ICT has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.* A successful EI shows three potential advantages for producers: a reduction in costs, a reduction in inventory and a reduction in their environmental impact [28]. Partners and participants in the

implementation project can benefit from: changing their existing plans, formulating future operations, updating of ICT and a good general technological standard allow for a fast and easy EI between the GSC components, integrating both internal and external business functions [6]. The return on investment also increases thanks to innovation in procedures, as do sales. The EI and ICTs have

Hypothesis 4. (H_4) *The integration of ICT has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.* Hypothesis 4. (H_4) The integration of ICT has a direct and positive effect when it comes to obtaining benefits served to demonstrate the importance of SCs, GSCs and updating of ICTs has also been identified as a key factor in order to achieve environmental sustainability as they facilitate: information line-up and planning, organizational environmental practices, the capacity to improve and allow for an effective compliance with environmental requirements [26]. Having taken the above into consideration, the following hypothesis is proposed:

Hypothesis 4. (H_4) *The integration of ICT has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.* Updating of ICT and a good general technological standard allow for a fast and easy EI between the GSC components, integrating both internal and external business functions [6]. The return on investment also increases thanks to innovation in procedures, as do sales. The EI and ICTs have served to demonstrate the importance of SCs, GSCs and updating of ICTs has also been identified as a key factor in order to achieve environmental sustainability as they facilitate: information line-up and planning, organizational environmental practices, the capacity to improve and allow for an effective compliance with environmental requirements [26]. Having taken the above into consideration, the following hypothesis is proposed:

Hypothesis 5. (H_5) *Updating of ICT has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.* **Hypothesis 5. (H_5)** *Updating of ICT has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.* Updating of ICT and a good general technological standard allow for a fast and easy EI between the GSC components, integrating both internal and external business functions [6]. The return on investment also increases thanks to innovation in procedures, as do sales. The EI and ICTs have served to demonstrate the importance of SCs, GSCs and updating of ICTs has also been identified as a key factor in order to achieve environmental sustainability as they facilitate: information line-up and planning, organizational environmental practices, the capacity to improve and allow for an effective compliance with environmental requirements [26]. Having taken the above into consideration, the following hypothesis is proposed:

Hypothesis 5. (H_5) *Updating of ICT has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.* Implementing a GSC in an organization entails a series of benefits, as this process is crucial to promote green thinking within an organization. Organizations currently have to maintain adequate levels of competitiveness whilst also following government, environmental and social requirements [29,30].

Hypothesis 5. (H_5) *Updating of ICT has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.* Implementing a GSC in an organization entails a series of benefits, as this process is crucial to promote green thinking within an organization. Organizations currently have to maintain adequate levels of competitiveness whilst also following government, environmental and social requirements [29,30]. Compliance with these types of regulations is essential when it comes to carrying out proactive ecological strategies needed to achieve environmental goals and an improved business image. To successfully implement a GSC however, it is fundamental that providers and customers take an active part [31,32]. Solid partnerships with providers and customers help in the adoption and development of innovative and environmentally-friendly technologies. Having taken the above into consideration, the next hypothesis is proposed:

Hypothesis 6. (H_6) *The implementation of GSC has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.*

Hypothesis 6. (H_6) *The implementation of GSC has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.* **Hypothesis 6. (H_6)** *The implementation of GSC has a direct and positive effect when it comes to obtaining benefits from the GSC when it is implemented.*

Figure 1 shows the association between the variables analyzed in this study; it indicates the number of items in each, which is discussed in the Methodology section of this manuscript.

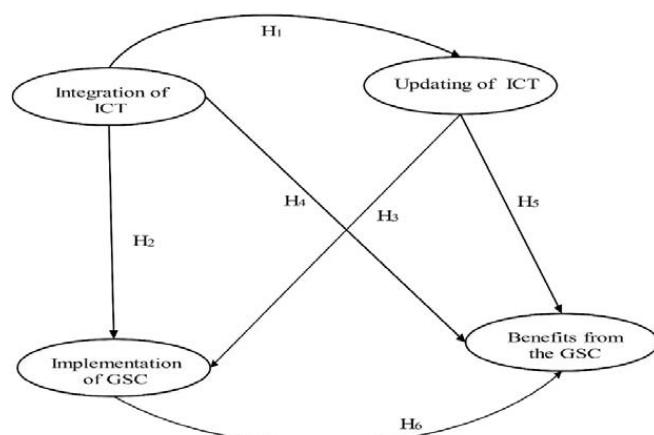


Figure 1. Hypothesis.
Figure 1. Hypothesis.

3. Development of Methodology

3.1. Phase 1. Sample Collection

To collect information and validate the model in Figure 1, a designed questionnaire has been used, one of the most used methods to gather information easily and quickly [33–35], as well as a deep revision of literature, which allows us to identify research related to the integration and updating of IT, the implementation and the benefits of a GSC, all considered LTV. The literature revisions a rational validation of the questionnaire and identifies the items.

Given that the questionnaire items were obtained from research carried out in different countries and industrial sectors, a group of green supply chain experts, including academics and engineers working in companies, evaluated the congruence, relevance, importance and language. This process represents a judges' validation and helped to adapt it to the context of the maquiladora industry [36,37].

The final questionnaire is divided into two parts. The first part is composed of twelve LTV, of which only four were taken to develop this research, defined as the LTV in Figure 1 and the items appear in Table 1. The items were responded to on a Likert scale with values of one to five, where one indicates very low or never and five indicates very high or always. The second section is a series of demographic questions such as the respondent's position, years of experience and so forth, which will help us characterize the sample.

Table 1. Items in the LTV.

Integration of ICT	Acronym
Use of ERP, CRM and Intranet with providers [12,19]	ITI1
EI is used in real-time with providers [11,19]	ITI2
There is an improved ICT line-up with providers [11,17]	ITI3
Use of EI across the entire organization [11,18]	ITI4
Use of ERP, CRM and Intranet with clients [12,19]	ITI5
Use of EI via ICT with clients [11,38]	ITI6
Improved ICT line-up with intelligent products [12,38]	ITI7
Feedback across all levels via ICT [18,19]	ITI8
Use of ICT in predictions with providers [11,17]	ITI9
Updating of ICT	
Use of the most up-to-date ecological ICTs [17,18]	UTI1
More modern ICT than the competitors [12,19]	UTI2
Investment in ICT to align their technology with that of its partners [12,19]	UTI3
Implementation of GSC	
Work on the product's life cycle (inverse logistics) [32,39]	IGSC1
GSC is considered a priority strategy [16,26]	IGSC2
Implement indicators to measure environmental impact [18,40]	IGSC3
Green initiatives are backed by superior management [39,40]	IGSC4
Savings are generated because of the GSC in energy, transport, storage and packaging [11,18]	IGSC5
The company's performance is better than its competitors when it comes to managing the GSC [8,41]	IGSC6
Environmentally-friendly products are designed [5,16]	IGSC7
Green initiatives are invested in even if they do not generate a return on investment (ROI) [8,42]	IGSC8
Green initiatives are evaluated over the entire SC [17,39]	IGSC9
Benefits from the GSC	
Reduced costs [9,11]	BGSC1
Increased sales [5,42]	BGSC2
Customer satisfaction [26,43]	BGSC3
Better ROI [5,11]	BGSC4
Increase in income [8,42]	BGSC5
Reduction in emissions/waste [11,40]	BGSC6
Improved business image [5,26]	BGSC7
Increase income through ecological products [5,16]	BGSC8
Product innovation [40,41]	BGSC9

The questionnaire is applied to the Mexican Maquiladora export industry, focusing on staff with at least one-years' experience on their job, so that the sampling is stratified into different categories. We set up appointments with managers to apply the questionnaire in a personal interview and the respondents later recommended the questionnaire to their colleagues and then a snowball sampling followed.

3.2. Phase 2. Capture and Debugging the Sample

The information is processed using statistic software called SPSS 24[®] and data is de-bugged with the aim of detecting atypical values and any missing values. These are replaced by the value of the median for each item due to its ordinal values [44]. In addition, we calculate the standard deviation in each case of the questionnaires applied to identify respondents who are not committed, where cases of values of lower than 0.500 on the standard deviation are eliminated [45].

3.3. Phase 3. Definition of LTV

Although the LTV in the questionnaire had already defined a list of items that integrated them, to demonstrate statistically that there was an association between the dimension and the items, a factorial analysis of the four variables analyzed was developed. A promax rotation is used to continue with the analysis of structural equations models and the factorial loads and the associated *p*-values of each item are analyzed. In this case, it is sought that the factorial loads are greater than 0.5 and that the *p* associated value is less than 0.05 [46,47].

3.4. Phase 4. Characterization of the Items

We carry out a characterization of the items which make up every of the LTV. We use the interquartile range (IR) as a measure of dispersion of the data, so the first and third quartile of data is calculated. High values specify that there is no consensus between the respondents in relation to the true value that that item should have but if the value is low, it specifies a consensus on its value [48]. The median is also used as a measure of central tendency and high values indicate that the respondents consider that item to be very important, while low values specify that the item is not very important to them [49].

3.5. Phase 5. Characterization of the Sample

Crossed tables are used for analysis on demographic data. These tables will serve to characterize the sample in terms of the gender of responders, the industrial sector to which they belong, the years of experience and the job position. These tables help to determine the level of experience that the respondents had and, therefore, the reliability of the information obtained, as well as to identify tendencies in responders.

3.6. Phase 6. Statistical Validation

For the statistical validation for the LTV in the model, we have used different indices, such as:

1. Average Variance Extracted (AVE) to determine the convergent validity, for which values of over 0.5 were expected [50].
2. Cronbach's Alpha and the reliability index to determine the reliability on the scale and values of over 0.7 are expected [51].
3. Full collinearity VIF to identify vertical and lateral collinearity, for which values lower than 5 are expected [52].
4. R-squared and R-squared adjusted to measure parametric predictive validity.
5. Q-squared to measure non-parametric predictive validity [52].

3.7. Phase 7. Design of Structural Equations Modelling

The model in Figure 1 is assessed by means of structural equations based on partial least squares (PLS), a multi-variate analysis technique used and applied in diverse research areas for example biology, medicine and engineering [53]. The software used to simulate the model is WarpPLS 5.0®, the algorithms of which are based on PLS and the use of which is recommended in small samples, unusual data or data obtained by means of a Likert scale [54].

Several efficiency indices are analyzed before the model interpretation, for example: average path coefficient (APC) to test the hypotheses, the average R-squared (ARS), average adjusted R-squared (AARS) for predictive validity, average variance inflation factor (AVIF) and average full collinearity VIF (AFVIF) for collinearity and the Tenenhaus GoF for data fit. The study established 0.05 as a maximum cut-off *p*-value for these indices; thus, inferences were made with a 95% confidence level, testing the null hypothesis that APC and ARS are equal to zero, versus the alternative hypothesis stating that APC and ARS are different to zero.

Three different types of effects are analyzed in the model; (1) direct effects (appearing in Figure 1 as arrows from an LTV to other); (2) indirect effects (given by paths with two or more segments); and (3) total effects (the sum of direct and indirect effects). Also, in order to determine their significance, the *p*-values were analyzed by comparing the null hypothesis $\beta_i = 0$, versus the alternative hypothesis $\beta_i \neq 0$ [55].

4. Results

4.1. Descriptive Analysis of the Sample

The survey is applied for 6 months and 326 questionnaires were obtained, of which only 284 were valid for the analysis after performing the debugging of the database, where 42 were eliminated because they contained missing data or uninvolved respondents were detected. Table 2 shows the crossed table, which compares the industrial sector and gender of the interviewees; first, it is observed that there was more participation from men than women, with a total participation of 194 men, who represent the 68.30% of the total sample and only 90 women, representing 31.69%. Likewise, it can be observed that 198 (69.71%) of the interviewees are from the two industrial sectors, 119 belonging to the automotive sector and 79 to the electrical/electronic sector.

Table 2. Industrial sector and gender.

Sector	Gender		Total
	Male	Female	
Automotive	77	42	119
Electric/Electronic	56	23	79
Other	15	8	23
Medical	13	6	19
Metalworking	13	3	16
Plastics	9	2	11
Communications	6	2	8
Textile	3	2	5
Services	2	2	4
Total	194	90	284

Table 3 shows the crossed table, which compares the position of the interviewees and their years of experience. It can be seen that 213 of the interviewees have a high hierarchical position, 139 are engineers and 74 are managers. Table 3 also indicates that 242 interviewees, that is 85.21%, have more than two years of experience in their position, which will help us validate the information obtained based on the experience of the interviewees.

Table 3. Job position and years of experience.

Job Position	Years of Experience					Total
	>1-<2	>2-<3	>3-<4	>4-<5	>5	
Engineer	12	23	18	36	56	139
Manager	2	4	11	22	35	74
Storekeeper	4	5	6	10	18	43
Technician	13	2	7	4	2	28
Total	42	51	31	25	135	284

4.2. LTV Generation

Table 4 illustrates the factorial analysis for the 30 items analyzed in the four latents. The factor loading of each item in all the LTV is illustrated and in the last column appears the *p* value for the statistical test of significance. Given that the factorial loads are greater than 0.5 in all the items and that the *p* value is less than 0.001, it is concluded that all the items have convergent validity in the variable that has initially been proposed, allowing to proceed to the model analysis.

Table 4. Factor loadings.

Items	LTV				<i>p</i> -Value
	Integration of ICT	Updating of ICT	Implementation of GSC	Benefits from the GSC	
ITI1	0.759	0.058	−0.141	0.134	<0.001
ITI7	0.8	−0.063	−0.035	−0.01	<0.001
ITI8	0.809	0.188	0.007	−0.003	<0.001
ITI9	0.74	0.095	0.016	0.022	<0.001
ITI2	0.773	−0.029	−0.105	0.081	<0.001
ITI3	0.806	0.002	0.157	−0.072	<0.001
ITI4	0.763	−0.051	0.088	−0.096	<0.001
ITI5	0.808	−0.051	−0.011	−0.012	<0.001
ITI6	0.818	−0.141	0.015	−0.036	<0.001
UTI1	−0.02	0.91	−0.066	0.056	<0.001
UTI2	0.051	0.922	0.075	−0.071	<0.001
UTI3	−0.031	0.922	−0.01	0.016	<0.001
IGSC2	−0.141	0.191	0.856	−0.018	<0.001
IGSC4	−0.039	0.04	0.885	−0.039	<0.001
IGSC6	0.065	−0.035	0.905	−0.034	<0.001
IGSC7	0.087	−0.131	0.875	0.033	<0.001
IGSC1	0.062	−0.06	0.825	−0.105	<0.001
IGSC3	−0.014	−0.004	0.866	0.043	<0.001
IGSC5	−0.044	−0.002	0.84	0.139	<0.001
IGSC8	0.142	−0.207	0.869	0.023	<0.001
IGSC9	−0.125	0.217	0.838	−0.042	<0.001
BGSC9	−0.065	0.061	0.024	0.844	<0.001
BGSC1	0.068	−0.044	−0.184	0.844	<0.001
BGSC7	−0.106	0.05	0.048	0.831	<0.001
BGSC5	−0.062	0.004	−0.185	0.854	<0.001
BGSC8	−0.063	−0.024	0.043	0.808	<0.001
BGSC4	0.064	−0.011	0.046	0.835	<0.001
BGSC6	−0.013	0.115	0.186	0.852	<0.001
BGSC2	−0.012	0.06	−0.089	0.817	<0.001
BGSC3	0.196	−0.222	0.116	0.801	<0.001

4.3. Characterization of the Items

The descriptive analysis of the items appears in Table 5 and is shown in descending order in accordance with the median value from the second column. We can see that 29 out of the total 30 items have a median greater than 4, which means that, according to the participants' perception, these items are the most significant and the ones they associate the most with the *Integration of ICT*, *Updating of ICT*,

and the GSC and that they can come to have a greater impact on their implementation. Finally, in the third column we can see the IR as a measure of dispersion.

Table 5. Characterization of the items.

Items Integration of ICT	Median	IR
ITI1	4.788	1.971
ITI5	4.607	2.003
ITI7	4.485	1.959
ITI9	4.470	2.093
ITI2	4.467	1.953
ITI8	4.396	1.979
ITI3	4.364	2.006
ITI6	4.273	2.024
ITI4	4.272	2.119
Updading of ICT		
UTI3	4.364	2.076
UTI1	4.327	2.075
UTI2	4.268	2.055
Implementation of GSC		
IGSC3	4.361	2.040
IGSC7	4.318	2.094
IGSC5	4.307	2.211
IGSC9	4.207	2.128
IGSC1	4.187	2.027
IGSC6	4.169	1.983
IGSC2	4.131	2.039
IGSC4	4.056	2.066
IGSC8	3.961	2.194
Benefits from the GSC		
BGSC2	4.865	1.762
BGSC1	4.702	1.972
BGSC7	4.700	2.019
BGSC6	4.664	2.025
BGSC9	4.625	2.003
BGSC4	4.497	2.011
BGSC5	4.483	2.107
BGSC8	4.322	2.096
BGSC3	4.136	1.659

4.4. Validation of LTV

The indices for validating LTV integrated in the model in Figure 1 appear in Table 6. We can see that the coefficients R-squared, adjusted R-squared and Q-squared are presented only for dependent LTV and that the values mentioned above are acceptable, as they are greater than 0.02, which means that the model has an adequate predictive validity (parametric and non-parametric). Similarly, the average variance extracted (AVE) is shown. We can see that all the LTV have values close to, or greater than 0.5, which specifies that the model has an acceptable convergent validity.

The reliability index and the Cronbach's Alpha coefficients are calculated for all LTV and it is observed that those values are greater than 0.7, so it is concluded that the LTV have an internal validity. Finally, we observe that all the LTV analyzed have a VIF value lower than 3.3, which specifies that there are no collinearity issues.

Table 6. Validation of LTV.

LTV Coefficients	Integration of ICT	Updating of ICT	Implementation of GSC	Benefits from the GSC
R-squared		0.526	0.412	0.599
Adj. R-squared		0.524	0.408	0.595
Q-squared		0.526	0.414	0.600
Avg. var. extract.	0.619	0.843	0.744	0.692
Cronbach's alpha	0.923	0.907	0.957	0.944
Composite reliab.	0.936	0.942	0.963	0.953
Full collin. VIF	2.358	2.475	2.457	2.463

4.5. Structural Equations Model

The model's results are shown in Figure 2, where each segment shows the association between two LTV and is shown using the β parameter and the p-value, while R-squared is used to measure the variance quantity explained in dependent variables, as well as indicating the combined loadings and the variance quantity explained in dependent variables, as well as indicating the combined loadings and the cross-loadings to determine the convergent validity of each of the items and the cross-loadings to determine the convergent validity of each of the items.

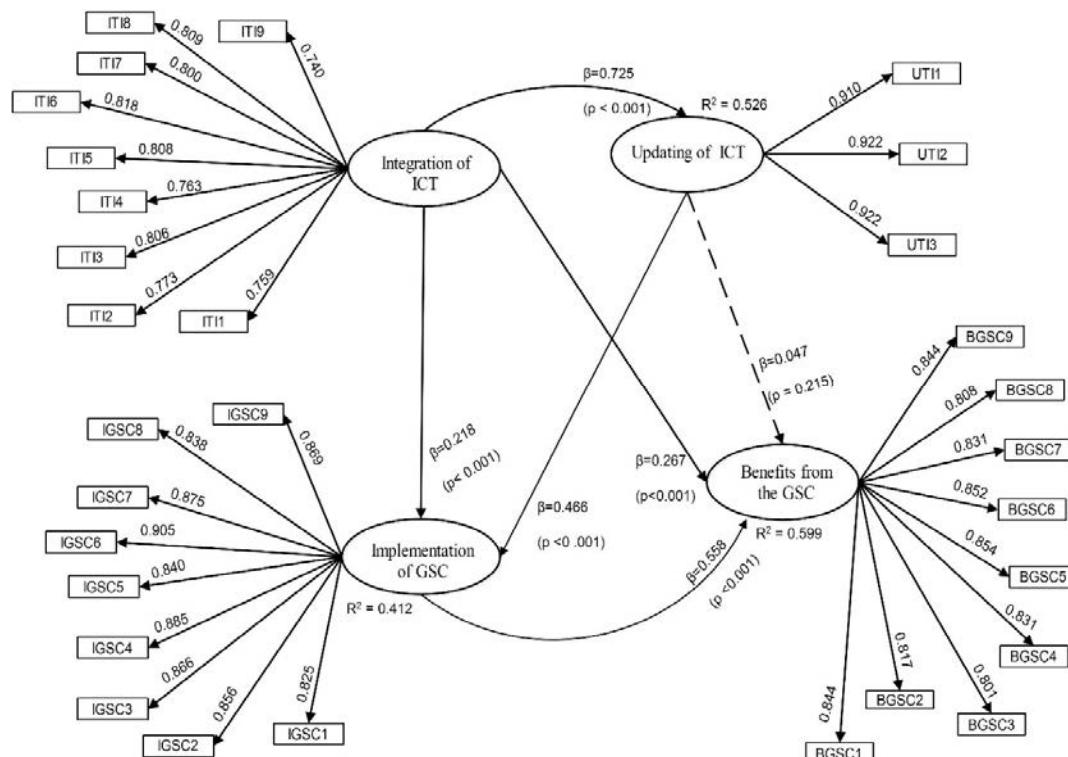


Figure 2. Model developed.
Figure 2. Model developed.

The efficiency indices obtained for the model are as follows and as it can be observed, they all meet the efficiency indices established for the model are as follows and as it can be observed, they all meet the cut-off values established:

- Average path coefficient (APC) = 0.380, $p < 0.001$
- Average R-squared (ARS) = 0.512, $p < 0.001$
- Average path coefficient (APC) = 0.380, $p < 0.001$
- Average adjusted R-squared (AARS) = 0.509, $p < 0.001$
- Average R-squared (ARS) = 0.512, $p < 0.001$
- Average block VIF (AVIF) = 2.110, acceptable if ≤ 5 , ideally ≤ 3.3
- Average adjusted R-squared (AARS) = 0.509, $p < 0.001$
- Average full collinearity VIF (AFVIF) = 2.438, acceptable if ≤ 5 , ideally ≤ 3.3
- Average block VIF (AVIF) = 2.110, acceptable if ≤ 5 , ideally ≤ 3.3
- Average full collinearity VIF (AFVIF) = 2.438, acceptable if ≤ 5 , ideally ≤ 3.3
- Tenenhaus GoF (GoF) = 0.609, small ≥ 0.1 , medium ≥ 0.25 , large ≥ 0.36

According to values in Figure 2, the structural equations obtained of the model are presented below:

- Updating of ICT = 0.725 Integration of ICT + Error
- Implementation of GCS = 0.218 Integration of ICT + 0.466 Updating of ICT + Error
- Benefits from the GSC = 0.558 Implementation of GSC + 0.267 Integration of ICT + 0.047 Updating of ICT + Error

4.5.1. Direct Effects in the Model

- Updating of ICT = 0.725 Integration of ICT + Error
- Implementation of GCS = 0.218 Integration of ICT + 0.466 Updating of ICT + Error
- Benefits from the GSC = 0.558 Implementation of GSC + 0.267 Integration of ICT + 0.047 Updating of ICT + Error

4.5.1. Direct Effects in the Model

Figure 1 displays the hypothesis considered in the initial model, the direct effects of this are illustrated in Figure 2 and this is used as a basis for the following conclusions:

H₁: There is necessary statistical certainty to say that the *Integration of ICT* has a direct and PE on the *Updating of ICT* within a GSC, since when the first LTV increases its standard deviation by one unit, the second does so by 0.725 units.

H₂: There is necessary statistical certainty to say that the *Integration of ICT* has a direct and PE on the *Implementation of GSC* since when the first LVT increases its standard deviation by one unit, the second does so by 0.218 units.

H₃: There is necessary statistical certainty to say that *Updating of ICT* has a direct and PE on the *Implementation of a GSC* since when the first LTV increases its standard deviation by one unit, the second does so by 0.466 units.

H₄: There is necessary statistical certainty to say that the *Integration of ICT* has a direct and PE when it comes to obtaining the *Benefits from the GSC* with its implementation, since when the first LTV increases its standard deviation by one unit, the second does so by 0.267 units.

H₅: There is not necessary statistical certainty to say that *Updating of ICT* has a direct and PE when it comes to obtaining the *Benefits from the GSC* with its implementation; this is stated with a 95% confidence level, as the associated p-value is greater than 0.05.

H₆: There is necessary statistical certainty to say that the *Implementation of GSC* has a direct and PE when it comes to obtaining the *Benefits from the GSC* with its implementation, since when the first LTV increases its standard deviation by one unit, the second does so by 0.558 units.

It is very significant to note the direct effect the LTV of the *Benefits from the GSC* has and that 59.9% of the time it can be explained by the variables *Integration of ICT*, *Updating of ICT* and *Implementation of GSC*. Its R squared has a value of 0.599, 16.2% of which stems from the variable *Integration of ICT*, 2.7% from the variable *Updating of ICT* and 41% from the LTV *Implementation of a GSC*. Using these findings as our base, we can conclude that organizations must prioritize the successful *implementation of GSC*, since it is what has the greatest impact and explanatory power when it comes to obtaining the *Benefits from the GSC*.

4.5.2. Indirect Effects in the Model

In the model assessed, which is illustrated in Figure 2, can be seen 4 indirect effects, defined as follows:

1. The LTV entitled *Integration of ICT* has an indirect two-segment impact on the LTV entitled *Implementation of GSC*, which is a result of the measurement variable *Updating of ICT*. Whereby, the indirect effect is of 0.338 ($p < 0.001$), which is statistically significant and can explain up to 18.8% of its variability.
2. The LTV entitled *Integration of ICT* has an indirect two-segment impact on the LTV entitled *Benefits from the GSC*, which comes about through the measurement variable *Updating of ICT* and *Implementation of a GSC*. Whereby, the indirect effect is of 0.155 ($p < 0.004$), which is statistically significant and can explain up to 9.4% of its variability.

3. The LTV entitled *Integration of ICT* has an indirect three-segment impact on the LTV entitled *Benefits from the GSC*, which comes about through the measurement variable *Updating of ICT* and measurement variable *Implementation of GSC*. In this case, the indirect effect is of 0.189 ($p < 0.001$), which is statistically significant and can explain up to 11.5% of its variability.
4. The LTV entitled *Updating of ICT* has an indirect two-segment impact on the LTV entitled *Benefits from the GSC*, which comes about through the measurement variable *Implementation of GSC*. Whereby, the indirect effect is of 0.260 ($p < 0.001$), which is statistically significant and can explain up to 15.2% of its variability.

Table 7 shows the sum of the total indirect effects—the sum of the effects of two and three segments which exist between the variables in the projected in Figure 1.

Table 7. Sum of Indirect Effects.

To	From	
	Integration of ICT	Updating of ICT
Implementation of GSC	0.338 ($p < 0.001$) ES = 0.188	
Benefits from the GSC	0.334 ($p < 0.001$) ES = 0.209	0.260 ($p < 0.001$) ES = 0.152

4.5.3. Total Effects in the Model

The totality of the indirect and direct effects affords the total effects, which are shown in Table 8. It is noteworthy that in three variables the direct effect is the same as the total effect, which indicates that there is no indirect effect and in the other three the sum of the direct and indirect effects is included. It is vital to note that the direct effect of *Updating of ICT* with the variable *Benefits from the GSC* is only 0.047 and that it was not significant with a 95% confidence level. The indirect effect via the variables of *Updating of ICT* and the variable *Benefits of GSC* is of 0.260; in other words, the indirect effect is much greater and more significant than the direct effect, which shows that a company must make sure they have all the most *updating ICT* equipment. This also becomes an advantage when it comes to the implementation and management of a GSC and are the only way to obtain its benefits.

Table 8. Total Effects.

To	From		
	Integration of ICT	Updating of ICT	Implementation of GSC
Updating of ICT	0.725 ($p < 0.001$) ES = 0.526		
Implementation of GSC	0.556 ($p < 0.001$) ES = 0.309	0.466 ($p < 0.001$) ES = 0.291	
Benefits from the GSC	0.611 ($p < 0.001$) ES = 0.372	0.307 ($p < 0.001$) ES = 0.179	0.558 ($p < 0.001$) ES = 0.410

5. Conclusions and Limitations

The model proposed and the six hypotheses, were valid with information from the Mexican manufacturing industry but their conclusions can be extended to the rest of this industrial sector in other countries, since in the Mexican manufacturing industry the sector is basically composed of companies from all around the world, such as United States of America, Germany, Japan, France, China and so forth.

Based on the results obtained, it can be observed that the *Integration of ICT* and *Updating of ICT* are related. This is because one complements the other, which is validated via H_1 , as the greatest

and most significant direct effect in the entire model, since keeping ICTs integrated and updated provides a platform that helps companies to exchange knowledge, align processes and achieve operational flexibility. Furthermore, the integration of ICT affects the efficiency and effectiveness of business processes within and beyond the boundaries of the organization and updated ICTs become an important advantage that is reflected in the efficiency of operations performance [26,56].

Additionally, it is very important to highlight that ICTs constitute an effective tool, which facilitates the *implementation of a GSC*. The above statement is proven through the total and significant effect, which the LTV Integration of ICTs has on the variable Implementation of a GSC. In addition to that, Gunasekaran, et al. [57] mention the importance of involving ICT in the *implementation of GSC*, since this allows the collaboration and exchange of data and information, generating agility in decision making. Besides, Lee, Ooi, Chong and Seow [22] mention that having ICT integrated and updated through a GSC, a series of financial, productive and environmental benefits are created only if the companies see the adoption and implementation of the GSC as an advantage.

Using ICTs of a high technological standard in the implementation and management of a GSC is a strategic priority [26]; these ICTs generate benefits for the supply chain in the long-term. It is important to recognize, however, that those benefits can only be obtained through the Implementation of a successful GSC, as it is the measurement variable in this case. This shows that the ICT is only important when applied to an ecological SC, and, according to Marinagi, et al. [58], the development of current ICT systems for GSC supports and accelerates all commercial activities, improving decision making and productivity, and, according to Marinagi, Trivellas and Sakas [20], can generate a competitive advantage throughout the SC.

The analysis of the relationship between the Implementation of ICTs in the Benefits from the GSC is also important. The direct effect was just 0.267 (see Figure 2) but the indirect effect was of 0.334, achieved through Updating of ICT and the Implementation of the GSC as mediator variables. The above shows the importance of ICTs but only if they are up-to-date and applied to green supply chains, as on their own, the benefits are minimal. In this way, there is a total effect between variables of 0.611, the second greatest observed.

Lastly, it is important to highlight that according to Luthra, Garg and Haleem [32], a GSC generates a series of economic benefits that will be reflected in the reduction of costs of products and processes. For example, social benefits will contribute to the protection of the environment and will create a level of awareness of the clients, which will help to increase the sales and can aid to achieve social performances and competitiveness factors. These benefits help to minimize ecological damage and generate a global economic benefit [59]. This statement is proven by the total and significant effect between the variable Implementation of a GSC and Benefits from the GSC.

The afore-mentioned results indicate that ICT investments must be duly implemented in supply chain and they must be implemented to an adequate technological update which allows for the visibility of the same. In addition, information must be exchanged in real-time (with providers, production system departments and clients) and they must follow all the rules and standards established by the country in which the company is located.

6. Future Studies

The success of a GSC depends on many factors and in this study, we have only considered the integration of ICT and its technological update. In future studies we will try to integrate factors associated to the level of education and training that staff have, as a high level of knowledge is needed in order to use these technologies—to reprogram them for other activities and adapt them to different production lines, as is pointed out by Jabbour and de Sousa Jabbour [59]. It is also intended to use the remaining information from the questionnaire to design more structural equations models and to follow up on this research with the association of other LTVs, such as the ICT flexibility.

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ARTÍCULO:

**THE ROLE OF GREEN ATTRIBUTES IN PRODUCTION
PROCESSES AS WELL AS THEIR IMPACT ON OPERATIONAL,
COMMERCIAL AND ECONOMIC BENEFITS.**

Article

The Role of Green Attributes in Production Processes as Well as Their Impact on Operational, Commercial, and Economic Benefits

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Abstract: This paper reports a second-order structural equation model composed of four variables: the green attributes before and after an industrial production process, the operating benefits, the commercial benefits, and the economic benefits. The variables are related by means of five hypotheses and are validated statistically with information obtained from 559 responses to a questionnaire applied to the Mexican maquila industry. The model is evaluated using the technique of partial least squares and the results obtained indicate that the green attributes before and after the production process have a direct and positive effect on the obtained benefits, mostly on the operational ones. It is concluded that companies that are focused on increasing their greenness level must monitor and evaluate the existence of green attributes in their production process to guarantee benefits and make fast decisions if required due to deviations.

Keywords: attributes; green manufacturing; benefits; green supply chain; sensitivity analysis

1. Introduction

Nowadays, taking care of the environment is a factor that may influence some industrial activities in a significant way, such as procurement, manufacturing, or distribution processes, as well as the green supply chain (GSC). In addition, companies are looking to incorporate more environmental issues such as industrial pollution prevention and control, sustainability, and investment in initiatives that are environmentally friendly [1]. The previous issues must be part of a long-term competitive strategy [2], since nowadays it is necessary to consider a GSC to minimize or eliminate (if possible) the negative effects that the traditional supply chain (SC) has on the environment.

Moreover, GSC allow used products to return to the production process, creating a cycle that will take advantage of all the available materials, minimizing natural resources used while reducing the environmental impact, which helps the green process in a SC to be progressively improved. In addition, the quality of the product and production processes is enhanced, reducing costs and expanding market fees through customers who are looking for clean manufacturers and products.

Likewise, green manufacturing (GM) can be considered one of the principal driving forces behind sustainable industrialized development. Consequently, researchers and industries have considered GM processes as a vital challenge [3] to develop new market opportunities as well as increase the benefits

that may be acquired while focusing on environmental aspects in industries [4]. Furthermore, GM is a system that integrates the design of products and processes that influence the planning and control of manufacturing, identifying, quantifying, evaluating, and managing the flow of environmental waste in order to minimize the impact on the environment [5]. Similarly, a properly designed GM system may reduce operating costs through the efficient usage of raw materials, energy, and work force, which adds value to a product.

GM implementation aims to produce economically viable products with minimal environmental effect, but including a social and economic impact [6]. Thus, GM can be defined as the ability to intelligently use natural resources for manufacturing, which is performed through the creation of products and proposals to achieve economic, environmental, and social objectives; consequently, the environment can be preserved, while continuing to improve the quality of human life. In other words, these processes are possible due to the implementation of new technologies, regulatory measures, and appropriate social behavior [7].

However, implementing a GM process is not an easy task, since some strict regulations and policies must be complied with, especially in developed countries [8]. The manufacturing industry is the main segment for energy consumption and pollution, being responsible for 84% of CO₂ emissions as well as 90% of energy consumption [3]; these figures are reported despite complying with requirements such as the continuous improvement on the environmental product design, the use of environmentally friendly raw materials, the reuse of products, and the elimination of waste after a product's useful life. In fact, it is known that GM implementation leads to the improvement of manufacturing performance, but also requires the development of an organizational structure to establish a relationship between the GM implementation and the benefits obtained to encourage organizations to adopt a GM [7].

Nevertheless, declaring that a company applies GM practices implies that it complies with a series of industrial requirements, where it is possible to determine its level of implementation by evaluating a list of attributes of its production process. Likewise, the fulfillment of these attributes must guarantee the obtaining of benefits, reflected in the production processes, in the expansion of the market, and, as a consequence, driving the better economic performance of the company. Therefore, this article is focused on quantifying the existing relationship between those attributes that allow us to characterize a GM process, as well as analyzing how they impact the benefits obtained.

The attributes and benefits obtained from the implementation of a GM process are briefly described below.

1.1. Green Attributes in a Production Process

A GM addresses basic aspects during its manufacturing process, such as reduction, reuse, recycling, remanufacturing, preserving, managing waste, protecting the environment, complying with regulations, controlling pollution, and a variety of related issues [9]. The fulfillment of the previous criteria allows us to determine quickly and easily if the manufacturing processes can be considered a GM process.

As a matter of fact, currently in the industry some attributes are used to identify whether a manufacturing process fulfills the characteristics that confirm it is a real GM system. In addition, these attributes work as a measure in GM implementation systems or to assess how green a manufacturing process is at a certain moment. In addition, several authors have tried to identify and investigate some attributes to evaluate GM processes. In this sense, the majority of researchers have identified certain attributes as "mandatory" for any GM process, such as; reduction of emissions and waste towards the environment, energy, water, and resources preservation, environmental certification, clean production, green products generation, technologies implementation, and reverse logistics [10].

Additionally, other authors have labeled these attributes as "vital" in the environmental innovation adaptation based on the technological innovation, environmental monitoring systems, and the environmental customer collaboration [11]; however, attributes that are focused on personnel, management, suppliers, and government commitment are also included [12]. Finally,

some authors have identified several attributes referred to as “key elements” on a GM process: green practices, green design, green purchasing or marketing, green packaging, ecological transportation, GSC management, reverse logistics, among others, as well as the total quality and life cycle management of a product [13].

Given that raw material suppliers play an important role in the sustainable performance of the company, a series of green attributes must be evaluated before the production process; the company does not have complete control of this, although they can be part of the supplier management program. On the other hand, there are attributes that occur during the production process over which the company has total control.

The attributes before production (ABP) are those attributes detected before starting the production process, and show the relationship between organizations and suppliers, as well as programs for the use and preservation of natural resources, green product design and processes, and the eco-business model. On the other hand, attributes during production process (ADP) are presented throughout the GM process; they usually include reduction of emissions, clean production process, use of green technologies, use of alternative or sustainable energies, green practices in productive processes, and the implementation of new technologies. In general, these attributes are essential and an opportunity for companies to maximize performance, quality, and profits from their production processes. Similarly, lean manufacturing tools, the use of total quality management philosophy (TQM), remanufacturing or reworking of products, green labeling, green practices in the distribution system, and social responsibility are also included in the ADP classification.

In a literature review, 24 attributes have been found that help determine the level of the GM implementation processes, including as follows:

Attributes before the process:

- There are programs for the use and preservation of natural resources [14,15]
- Green purchases [16,17]
- There is an environmental certification or ISO 14001 [18–20]
- Green process design [19,21]
- Environmental collaboration with suppliers [12,16]
- Eco-business models [12,17]
- Use of environmentally friendly raw materials [17]
- Selection of green suppliers [18,22,23]
- Green product design [8,24]
- Green practices in provisioning [19,25].

Attributes during the process:

- Reduction of emissions towards the environment [21,26]
- Lean manufacturing tools are implemented [7,17]
- There is a clean production process [10,12]
- Green technologies implementation [16,27]
- Use of alternative or sustainable energies [7,15]
- Damage towards the environment is reduced [16,28,29]
- Green practices in productive processes [12,25]
- New technologies implementation [8,24]
- TQM philosophy implementation [30,31]
- Green labeling or eco-labeling [32,33]
- Remanufacturing of products [16,17]
- Green practices in the distribution system [19,25]
- Social responsibility [12,20,24].

However, there are also trends to investigate which attributes are having an impact on production costs that may lead to an increase in the number of customers for companies, and consequently, companies may improve their income [34]. Therefore, some managers believe that the objective of generating wealth is lost when using ABP and ADP, which is the purpose the company was created for [35]. As a result, if those attributes represent a financial cost to the company, the question that must be asked is: What are the benefits that a company may obtain when implementing these GM practices? The following section presents an answer to that question.

1.2. Benefits of a Green Manufacturing Process

The search for environmental improvements is generally associated with rising costs at the beginning of a sustainable environmental manufacturing implementation [30]. It is a common belief that the costs of energy, products, inputs, and regulatory pressure will increase when ADP are monitored [36]. However, if there are changes of paradigms in the industrial structure towards an increasingly green future, it is possible to identify a series of benefits on different aspects.

Furthermore, researchers have shown that there are positive impacts from GM on environmental, commercial, economic, operational, and social performance that have led to the reduction of raw materials costs, energy, and labor, adding better value to the final product, improving production efficiency, increasing market fees, social corporation image, as well as minimizing waste and pollution [37]. Likewise, substantial improvements are made in the company's organization and technology, helping to reduce the use of resources, which suggests better choices in the use of alternative materials and energy [11], eliminating the generation of wastewater, CO₂ and heat emission, as well as residual sounds [38].

Finally, the most important benefit is that green growth may help to link sustainability with the economic performance [22], which is the reason why the manufacturing industry has confirmed that there is a significant relationship between a reduction in emissions and improvements in financial performance, thus generating short- and long-term economic gain [37]. A list of the benefits obtained from the GM implementing processes, which some authors have supported, is given below, structured into three categories:

Operating Benefits:

- Increase the quality of their processes [15,39]
- Product design improvement [18,40]
- Increase technological innovation [11,41]
- Greater competitiveness, productivity, and efficiency [18,19]
- Optimization in the use of available resources [12,42]
- Low product rework [8,43]
- Increase the quality of the final product [9,18].

Commercial Benefits:

- Local market expansion [18,33,44]
- Better customer service [3,45,46]
- Increase the number of products classified as green [47,48]
- Greater environmental certifications [9,33].

Economic Benefits:

- Increase in sales [16,49]
- Increase in economic gains [9,24]
- Reduction of marketing costs [3,12]
- Reduction of material waste [37,42]

- Reduction of production costs [10,50,51]
- Reduction of workforce for reprocessing [43,52]
- Cost reduction for guarantees [18,40].

1.3. Research Problem, Objective, and Contribution

Nowadays, a GM process is not just a competitive advantage but a necessity to mitigate the effects of the manufacturing industry on the environment. However, companies wonder: is it profitable to change from a traditional manufacturing process to a GM process? Is there any new, easy, and fast way to make the transformation to a GM process? and, of course, Should attributes be measured in a production process to know the level of implementation of GM?

Although the existing literature deals with the green attributes that must be monitored before and after the production process, as well as the benefits obtained, the relationship between them is unknown, which has been the reason many GM implementation processes were abandoned. Therefore, a study based on empirical data that relate those attributes present in the production processes with the benefits is needed.

In order to answer the previous questions and the problems posed, the objective of this research is to design a second-order structural equations model that relates the green attributes to the benefits obtained by implementing a GM process, which facilitates decision-making in industry when transforming a traditional manufacturing process into a GM process.

In the research into those relationships between attributes and benefits of a GM process, our contributions are as follows: (i) Two new classifications of green attributes are presented, the attributes before the process (ABP) and the attributes during the process (ADP); in addition, this classification of attributes allows us to demonstrate a close and significant relationship between the green attributes that a GM process must have, which have been identified as necessary, mandatory, or vital; the reason is that, when reviewing previous works, mention is only made of simple attributes or requirements, but they have not been related to each other; (ii) 18 benefits have been identified and classified, taken from previous works related to the implementation of a GM process, and classified into three categories: operational, commercial, and economic benefits; (iii) the relationship between the ABP and ADP green attributes and operational, commercial, and economic benefits is presented and quantified; (iv) an easy, fast, and novel way for organizations to monitor their GM implementation process is provided.

The article is divided into six main sections. After this introduction, Section 2 presents the research hypothesis and the literature review; Section 3 presents the materials and methods; Section 4 presents the results; Section 5 exposes the industrial and academic implications; and, finally, Section 6 presents the conclusions of the research.

2. Hypothesis and Literature Review

ABP and ADP in a GM process are used to evaluate the green implementation level; these attributes allow for the generation of a significant change in a corporation's operational, and environmental objectives, as well as maximizing the *Operating Benefits* (OB) for organizations. As a result, these will be reflected almost instantly in the innovation of green products and processes [53], such as product quality, technological innovations [28], competitiveness improvement, productivity and efficiency of operations [54], time reduction in a product cycle and reprocess, increase of the quality of processes, and final product [13].

Fortunately, several world-class companies have changed their traditional production processes to GM processes voluntarily, based on the ABP and ADP control [40]. In addition, they have been implemented without analyzing their importance, since these attributes directly assess the potential impacts of their factories, facilities, and operations in the environment. They also involve an active change in the social environment, generating a series of benefits that are reflected in their organizations. Therefore, the following hypothesis is proposed:

Hypothesis H1. *Attributes before and during a Green Manufacturing Process* have a direct and positive effect on the *Operating Benefits* obtained by implementing GM practices.

Ji, et al. [55] mention that supplier collaboration through ABP is one of the most important GM business practices, crucial for the efficiency of green practices, as it helps companies to achieve greater performance in terms of flexibility, delivery time, quality, and costs. Similarly, other authors indicate that ABP and ADP are useful through environmental certification or ISO 14001, eco-business models, use of alternative or sustainable energies, use of TQM philosophy, and eco-labeling, which can be implemented to evaluate GM processes and practices commercially [5], because they are focused on innovation and green business design to improve production efficiency by reducing costs while presenting a green reputation as well [56].

Theoretically, the improvement of traditional manufacturing processes with a GM process may be fundamental to decide when to charge a higher price for a product or ensure wider market coverage, as well as fulfill customers' or clients' requirements while maintaining environmental awareness [16]. In addition, it supports local and global market expansion, better customer service, and a better reputation with customers and competitors, which leads to an updated company, product image, and product itself [57]. Therefore, the following hypothesis is proposed:

Hypothesis H2. *Attributes before and during a Green Manufacturing Process* have a direct and positive effect on the *Commercial Benefits* obtained by implementing GM practices in the production process.

Furthermore, several empirical findings have confirmed a positive relationship between GM and improvement in the operational performance in an organization [35]. Additionally, the GM is closely related to environmental management and achievements from ecological operating objectives. GM also stimulates the generation of *Operating Benefits* since the use of ecologically innovative products and processes not only reduces the negative environmental impact, but also increases a company's economic and social performance through the reduction of waste and costs [28]. Finally, the achievement of these *Operating Benefits* promotes a better corporate image, market penetration, and strengthening of the brand to outperform the competition [58].

As a matter of fact, consumers realize that the improvement in the environmental characteristics of a product is associated with high quality, so it is assumed that it will have a higher price. However, the GM process improvements may encourage real quality improvements as well as provide affordable prices to customers [59]. In addition, it has been demonstrated that continuous improvement in capabilities that support environmental improvements generate positive effects in terms of product quality [35]. Therefore, the following hypothesis is proposed:

Hypothesis H3. *Operating Benefits* have a direct and positive effect on the *Commercial Benefits* obtained by implementing GM practices in the production lines.

GM processes are considered a competitive tool to achieve a positive corporate image, a reduction in costs, an improvement in market perception, improvements in the process, and a better product quality [55]. Moreover, it is crucial to address economic and environmental aspects simultaneously [58]. However, after investing money in environmental topics, companies expect to obtain *Economic Benefits* in a shorter period of time [60].

In the same way, *Economic Benefits* refer to a reduction of production costs, workforce for reprocessing aspects, and costs for guarantees, among others; However, the *Economic Benefits* go along with the *Operating Benefits* obtained in a GM process, since at the same time as improving the product, competitiveness, productivity, and efficiency of the processes, production will be improved as well and, consequently, less waste and pollution will be generated [38]. Therefore, the following hypothesis is proposed:

Hypothesis H4. *Operating Benefits* have a direct and positive effect on the *Economic Benefits* obtained by implementing a GM process.

Similarly, companies need to obtain greater income with the minimal environmental impact as well as use raw materials that have a minimally negative effect on the environment and society—but the product must still be economically viable [61]. Thus, the search for *Economic Benefits* will not be only focused on manufacturing operations, but also on the marketing and distribution of the product, as a strategy to encourage the consumption of green products among customers [62]. Likewise, by achieving greater *Commercial Benefits* with the increase in the number of products classified as green and environmentally friendly [33], *Economic Benefits* are generated and measured by the increase in sales and economic profits. In that case, the development of processes, products, and green distribution will be competitive advantages in the market to maximize *Commercial Benefits*, *Economic Benefits*, and green GM [63]. Therefore, the following hypothesis is proposed to maximize *Commercial Benefits* and *Economic Benefits* with GM [61]. Therefore, the following hypothesis is proposed:

Hypothesis H5. *Commercial Benefits* have a direct and positive effect on the *Economic Benefits* obtained by implementing a GM process.

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The five hypotheses that have been presented are represented graphically in Figure 1, where the dependence of the variables (represented by ellipses) is illustrated by arrows.

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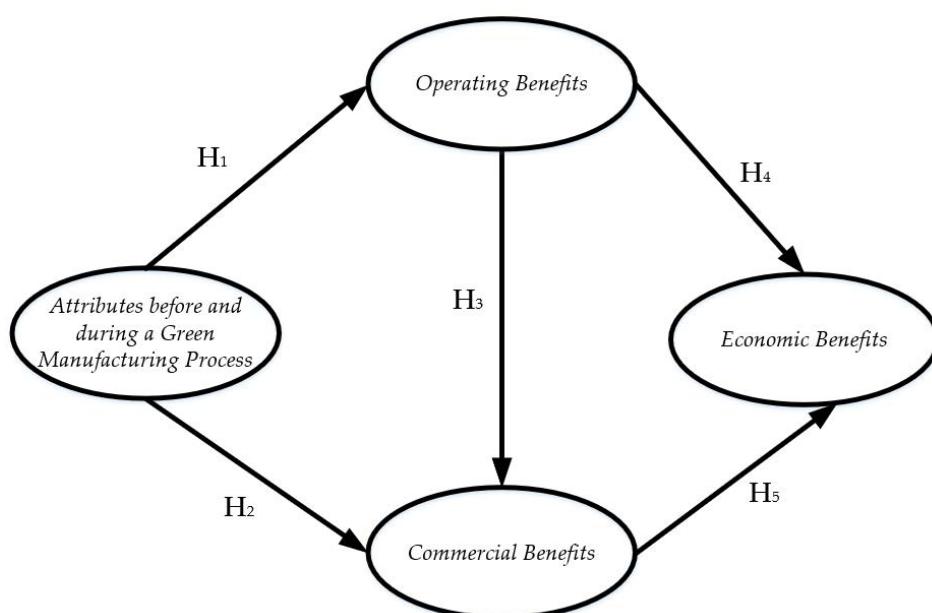


Figure 1. Proposed hypotheses.
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3. Materials and Methods

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In order to validate the five hypotheses that have been proposed, data from the industrial sector is required; therefore, for this purpose, a questionnaire is designed, data are collected, and the model is validated. The developed activities are shown below.

3.1. Literature Review

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An in-depth review of the literature is carried out as a universal method in the development of research. To in-depth validate the literature, the author used a date search method [1] to identify aspects research is carried out privately and published separately [57] and the literature information [1] to identify period spent 1995 to 2018 using previously published research [58]. The library, such as ScienceDirect for the period from 1995 to 2018 using more than 100 articles obtained from databases, such as ScienceDirect, EBSCOhost, or Ingenta, among many others, and using keywords such as “green production process,” “green attributes,” “operational benefits,” “commercial benefits,” and “economic benefits.”

This in-depth literature review was based on previous works conducted by authors such as Sarkis [26,64,66], Tseng [23,44], and Govindan [29,67], among others, who allowed us to identify the most used green attributes and the benefits that can be obtained when applying GM.

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3.2. Survey Design

To collect information and validate the latent variable and model, we used a designed questionnaire, one of the most used methods to gather information easily and quickly [64]. The questionnaire had three sections: the first aimed to get sociodemographic information from participants and companies, the second included the green attributes (before and during the GM process), and the third described the benefits obtained from the GM implementation process. Similarly, a first draft was evaluated by academic judges and managers working in manufacturing companies to make a better adjustment to the geographical context; they must say whether the questionnaire is easy to understand and if there are linguistic issues or special words for a certain industrial sector. This review process by academics and industry personnel provides necessary validation for the questionnaire before it is applied to the manufacturing sector [67].

3.3. Data Acquisition

Each item in the questionnaire must be answered using a Likert scale with values between 1 and 5, where 1 indicates that the attribute is not present in the production process or that the benefit is not obtained, and 5 indicates that the attribute is always present or that the benefit is always obtained. In addition, the questionnaire is applied to personnel who have at least one year of experience in their job position, have working experience in manufacturing companies, have participated in GM implementation practices, and have knowledge about the results obtained from their projects. Consequently, the sampling is initially stratified and focused on personnel with previous manufacturing experience; however, the snowball technique is included as some respondents recommend that other colleagues answer the questionnaire as well.

Furthermore, possible participants are identified using information from AMAC (Maquiladora Association, A.C.) in Ciudad Juarez (Mexico). Therefore, each candidate was contacted by e-mail to arrange an appointment for the interview and answer the questionnaire in a face-to-face manner; if an appointment was cancelled for any reason, a new appointment was agreed, but after three missed appointments that case was discarded.

3.4. Statistical Debugging

The data collected through the applied surveys are registered in a database created in Software SPSS 24® software, because of its easy data analysis and integrated commands; each row represents a case or questionnaire, while a column represents an observed variable or item. In addition, the data are debugged and screened before performing any type of analysis, where the main activities are [68]:

- Identifying missing values that were not answered in the survey; if the percentage of missing values is under 10%, then it is replaced by the median of the item; however, if the percentage is higher, then that questionnaire is discarded.
- Identifying extreme values in each item in order to replace it with the median, since the values obtained are on a Likert scale.
- Identifying uncommitted respondents by estimating the standard deviation in every questionnaire; cases with a standard deviation under 0.35 are discarded.

3.5. Data Validation

Once the data have been debugged, they are validated through different indexes. In this case, the model in Figure 1 illustrates four latent variables, which are integrated by other variables called items or observed variables. Therefore, the validation and their measured indexes in each latent variable are:

- R^2 and adjusted R^2 are estimated to measure the predictive validity of the model, where values greater than 0.2 are required [60].
- Q^2 is estimated to measure the non-parametric predictive validity and values greater than zero and similar to R^2 are expected [13].
- The Cronbach's alpha and composite reliability index are used to measure the internal reliability, which requires values greater than 0.7 [64]; these indexes are obtained iteratively, since sometimes by eliminating any attributes or benefits, their values increased.
- The Average Variance Extracted (AVE) is used to measure the convergent validity, where values greater than 0.5 are required [28].

For the integration of the attributes and benefits in the latent variables analyzed in the model of Figure 1, a factorial analysis is carried out using the technique principal components technique with a PROMAX rotation, which is excited iteratively. The items that have a factorial load less than 0.5 are eliminated due to the low association with the latent factor or variable. In addition, Z values are estimated for the statistical test of the factorial load of the items (attributes and benefits) and their confidence interval is obtained for a confidence level of 95%.

3.6. Statistical Description of the Sample

The description of the sample is necessary in order to get relevant sociodemographic data from participants as well as the industrial sector where they are currently working, such as: years of experience, industrial sector, job position, and gender. Crosstabs are used to analyze the demographic characteristics of the sample to identify trends.

3.7. Development of the Structural Equation Modelling

In order to validate the hypotheses presented in Figure 1, the structural modeling equation (SEM) technique based on Partial Least Squares and integrated in the WarpPLS 6.0® software is used, because some latent variables have a double role as independent and dependent variables. Therefore, this technique is recommended when the data do not have a normal distribution, which appears in an ordinal scale or when there is a small sample size [69].

In addition, SEM allows researchers to evaluate or validate theoretical models, making it one of the most powerful tools for the study of causal relationships on non-experimental data when these relationships are linear. Furthermore, SEM is a novel technique and is currently used in different fields [70]; for instance, Farooq, et al. [71] analyze the impact of the quality service on customer satisfaction, Ojha, et al. [72] analyze the SC organizational learning, exploration, exploitation, and firm performance, and Qi, et al. [73] analyze the impact of operations and SC strategies on integration and performance, among many others researchers.

Partial least squares regression is estimated according to Equations (1) and (2) [74]:

$$X = TP^T + E \quad (1)$$

$$Y = UQ^T + F, \quad (2)$$

where X is an $n \times m$ matrix of predictors, Y is an $m \times l$ matrix of responses; T and U are matrices that are, respectively, projections of X (the X score, component or factor matrix), and projections of Y (the Y scores); P and Q are, respectively, $m \times l$ and $p \times l$ orthogonal loading matrices; and E and F matrices are the error

terms, which are assumed to be independent and identically distributed in randomly normal variables. Also, the decompositions of X and Y are made to maximize the covariance between T and U.

As a regression technique, the PLS idea is to generate a dependence measure between latent variables, which can be a simple regression or a multiple regression, depending on the number of independent latent variables that explain a dependent variable. The objective is to obtain a linear equation, as illustrated in Equation (3):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p, \quad (3)$$

where:

Y is a dependent latent variable

β_0 is the regression coefficient for the intercept

β_i values are the regression coefficients (for independent latent variables 1 to p) that have a direct effect on Y .

Specifically, WarpPLS 6.0® software reports and use standardized values for the β estimation, and then the $\beta_0 = 0$, simplifying Equation (3) into Equation (4):

$$Y = \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p + E, \quad (4)$$

where E represents an estimation error. The statistical validation for a hypothesis is carried out through the β value in direct effects, as appears in Figure 1, where the null hypothesis (H_0) is represented by Equation (5), and alternative hypothesis (H_1) is represented by Equation (6):

$$H_0 : \beta_i = 0 \quad (5)$$

$$H_1 : \beta_i \neq 0. \quad (6)$$

The statistical test for β is done at a 95% confidence level. A hypothesis is accepted if the p -value associated is lower than 0.05, or the Z-value associated to the β significance test is bigger than 1.96, corresponding to a two-tailed test. In addition, a confidence interval for β value is estimated, looking to have intervals excluding the zero. The confidence intervals are estimated according to Equation (7) for the lower bound and Equation (8) for the upper bound:

$$\beta_{\text{low}} = \beta_i - 1.96 \text{ SE} \quad (7)$$

$$\beta_{\text{up}} = \beta_i + 1.96 \text{ SE}, \quad (8)$$

where:

β_i is the estimated value for a relationship between two variables;

1.96 is the Z value for a 95% confidence value for a two-tailed test;

SE is the standard error for β_i .

Three different types of effects are estimated in the structural equation model, and every relationship between latent variables has a β value linked. The effects measured in the model are: the direct effects that help to validate the hypotheses, which are represented by arrows in Figure 1, the total indirect effects that are presented when there are mediating variables, which require two or more segments, and the total effects that represent the sum of the direct and indirect effects.

In addition, it is important to mention that the variable called *Attributes before and during a Green Manufacturing Process* is a second-order variable, since there is a set of attributes that are present before the GM process, which represents a latent variable, while the attributes during the production process represent a second variable.

Six quality model indexes are obtained before interpreting the model [75]:

- Average path coefficient (APC), where p -associated values under 0.05 are required.
- Average R-squared (ARS) and Average Adjusted R-squared (AARS), which require p -associated values under 0.05.
- Average block variance inflation factor (AVIF) and Average full collinearity VIF (AFVIF), which require values under 5.
- Tenenhaus GoF Index (GoF) that estimates the data adjustment in the model, which requires values over 0.36.

In Figure 1 some dependent latent variables are explained by two or more latent variables. Therefore, in the present research the R^2 value is disintegrated according to the portion of variance that each independent variable explains, which is called effect size (ES) and allows for separating the essential variables from the trivial ones.

3.8. Sensitivity Analysis

A sensitivity analysis is reported in order to know the effect that a possible change in an independent variable has on a dependent variable. In partial least square the values of the latent variables are standardized, so it is possible to estimate the probabilities of occurrence among them. In this case, it is assumed that a standardized value greater than 1 represents a “high” probability of occurrence, while a value less than -1 represents a “low” probability of occurrence. Therefore, for each hypothesis an analysis is done regarding the four stages where the variables may be involved.

Specifically, this study analyzes the probabilities of occurrence simultaneously in each scenario is represented by “&”, while the conditional probability is represented by “if”.

4. Results

4.1. Demographic Data of the Sample

After four months of sampling, 559 valid questionnaires were obtained, once the statistical purification was applied; Table 1 presents descriptive information of the sample. In the first column the demographic data are presented, such as: gender, industrial sector and years of experience in their work position. In the second column the frequency of the answers of the participants is presented; for example it can be seen that 362 people of the total of the respondents were men, 190 women, and seven people did not specify their gender.

Table 1. Sample characterization.

	Demographic Data	Frequency	%
Gender	Male	362	64,758
	Female	190	33,989
	*NOS	7	1252
	** T = 559		T = 100
Industrial Sector	Automotive	342	61,180
	Plastics	72	12,880
	Metal—mechanical	49	8766
	Medical	34	6082
	Electronic	30	5367
	Electric	19	3399
	Aeronautics	7	1252
	NOS	6	1073
	T = 559		T = 100
Years of experience in the work position	2–5	185	33,095
	6–10	128	22,898
	1–2	119	21,288
	10–20	97	17,352
	20–30	28	5009
	NOS	2	0.358
	T = 559		T = 100

* NOS = Not specified, ** T = Total.

In the third column the percentage response of the participants is presented; returning to the previous example, it can be seen that 64.76% of the participants were men, 33.99% women, and 1.25% did not specify their gender. See Table 1 for a complete summary of the other demographics mentioned above.

4.2. Latent Variables Validation

Table 2 shows a summary of the validation indexes for the latent variables integrated in Figure 1. In the first column the validity indices of the latent variables are presented, such as R^2 , or adjusted R^2 , among others. In the second to fifth columns the values of the respective coefficients for each of the latent variables are presented. Finally, the interpretation and validation of each of the coefficients presented in the first column of Table 2 is presented.

Table 2. Indexes for latent variables validation.

Latent Variable Coefficients	Attributes before and during a Green Manufacturing Process	Operating Benefits	Commercial Benefits	Economic Benefits
R^2		0.371	0.705	0.737
Adj. R^2		0.370	0.704	0.736
Composite Reliability	0.942	0.940	0.909	0.952
Cronbach's Alpha	0.877	0.925	0.866	0.941
AVE	0.890	0.690	0.714	0.737
Full Collinearity VIF	1.772	3.928	4.026	3.764
Q^2		0.372	0.705	0.738

The latent variables have parametric and non-parametric predictive validity with R^2 and adjusted R^2 values greater than 0.2; however, the Q^2 value is greater than zero, and very similar to R^2 , which leads us to conclude that there is enough non-parametric predictive validity.

Additionally, it is observed that the AVE values are greater than 0.5, which indicates enough convergent validity. On the other hand, the latent variables have internal reliability, since the values for Cronbach's alpha index and the composite reliability are greater than 0.7. Finally, it is observed that the latent variables do not have problems of multicollinearity, since the VIF values are less than 5. According to previous index values, it is concluded that the latent variables are suitable to be integrated in the structural equation model.

In Appendix A appears a list of attributes and benefits that integrates every latent variable, the Z ratios for the statistical test, and the confidence interval for every factor loading regarding the factor analysis. Some attributes or benefits were eliminated from the analysis due to low factor loadings, and therefore the appendix only illustrates the final list.

4.3. Structural Equation Model

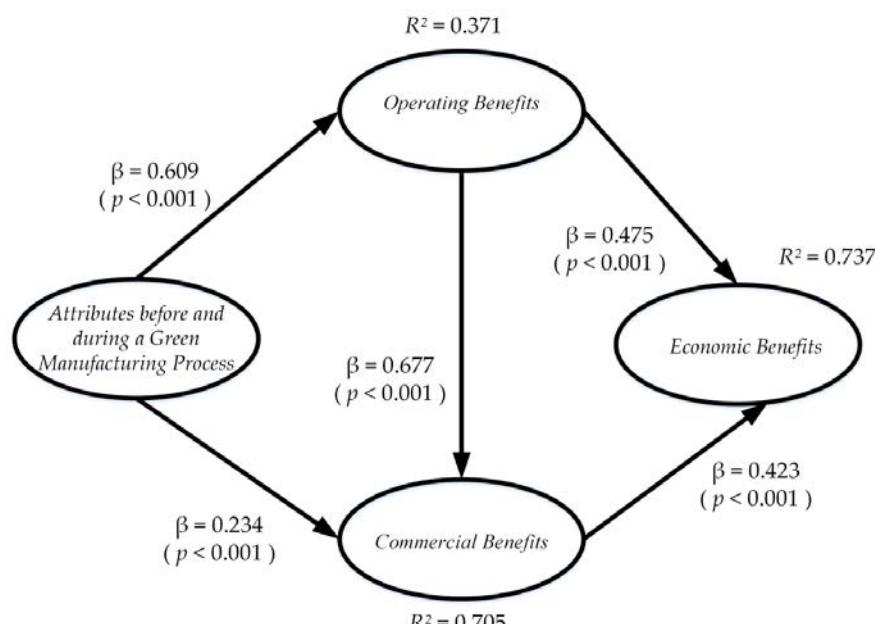
Table 3 illustrates the indexes of validation obtained from the structural equation model after it was introduced and analyzed in the Software WarpPLS 6.0®. Observe that the APC, ARS, and AARS indexes comply with their approval values since the p -value is lower than 0.001. Similarly, the AVIF and AFVIF indexes have values lower than 5, the maximum allowed value, which indicates that there are no multicollinearity problems. Also, the Tenenhaus GoF (Goodness of Fit) index suggests that the model has enough explanatory power, since it has a value greater than 0.36. According to the previous values in indexes, it is concluded that the defined model is valid and can be interpreted.

Table 3. Indexes for model validation.

Indexes for the Model Validation
Average path coefficient (APC) = 0.484, $p < 0.001$
Average R-squared (ARS) = 0.604, $p < 0.001$
Average adjusted R-squared (AARS) = 0.603, $p < 0.001$
Average block VIF (AVIF) = 2.379, acceptable if ≤ 5 , ideally ≤ 3.3
Average full collinearity VIF (AFVIF) = 3.373, acceptable if ≤ 5 , ideally ≤ 3.3
Tenenhaus GoF (GoF) = 0.677, small ≥ 0.1 , medium ≥ 0.25 , large ≥ 0.36

Figure 2 illustrates the evaluated structural equation model, where the β values are indicated for each relationship among latent variables (hypotheses) and the associated p -value in order to determine their statistical significance. Appendix B illustrates the Z ratios for β values statistical test indicating that every value is higher than 1.96 according to the established confidence level. Also, Appendix B illustrates the confidence intervals for every β in direct effects and, according to that information, every hypothesis is accepted.

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**Figure 2.** Evaluated model.

Considering the p -values and β values in each relationship among the latent variables and considering that the confidence level is 95%, the conclusions about the five hypotheses presented in this research are as follows:

H1: There is enough statistical evidence to declare that *Attributes before and during a Green Manufacturing Process* have a direct and positive effect on the *Operating Benefits* obtained by implementing GM practices, because when the first latent variable increases its standard deviation in one unit, the second one goes up by 0.609 units.

H2: There is enough statistical evidence to declare that *Attributes before and during a Green Manufacturing Process* have a direct and positive effect on the *Commercial Benefits* obtained by implementing GM practices in the production lines, because when the first latent variable increases its standard deviation in one unit, the second one goes up by 0.234 units.

H3: There is enough statistical evidence to declare that *Operating Benefits* have a direct and positive effect on the *Economic Benefits* obtained by implementing GM practices in the production lines, because when the first latent variable increases its standard deviation in one unit, the second one goes up by 0.475 units.

H4: There is enough statistical evidence to declare that *Commercial Benefits* have a direct and positive effect on the *Economic Benefits* obtained by implementing a GM process, because when the first latent variable increases its standard deviation in one unit, the second one goes up by 0.423 units.

H5: There is enough statistical evidence to declare that *Commercial Benefits* have a direct and positive effect on the *Economic Benefits* obtained by implementing a GM process, because when the first latent variable increases its standard deviation in one unit, the second one goes up by 0.423 units.

H_4 : There is enough statistical evidence to declare that *Operating Benefits* have a direct and positive effect on the *Economic Benefits* obtained by implementing a GM process, because when the first latent variable increases its standard deviation in one unit, the second one goes up by 0.475 units.

H_5 : There is enough statistical evidence to declare that *Commercial Benefits* have a direct and positive effect on the *Economic Benefits* obtained by implementing a GM process, because when the first latent variable increases its standard deviation in one unit, the second one goes up by 0.423 units.

According to the information in Figure 2, there are three dependent variables, and therefore the structural equations can be stated as follows:

$$\text{Operating Benefits} = 0.609 \text{ Attributes before and during a Green Manufacturing Process} + \text{Error} \quad (9)$$

$$\text{Commercial Benefits} = 0.234 \text{ Attributes before and during a Green Manufacturing Process} + 0.677 \text{ Operating Benefits} + \text{Error} \quad (10)$$

$$\text{Economic Benefits} = 0.475 \text{ Operating Benefits} + 0.423 \text{ Commercial benefits} + \text{Error}. \quad (11)$$

Table 4 presents in more detail the hypotheses and their results. In the first column the number of the hypothesis is presented; in the second and third columns the independent and dependent variables are presented, respectively; in the fourth and fifth columns the indices β and R^2 (used as part of the validation of the hypotheses) are presented, and in the sixth column the p -value is presented. The p -value is evaluated with a confidence level of 95%, to reject or accept the hypothesis. Finally, in the last column, the conclusion of rejection or acceptance of the hypothesis is determined.

Table 4. Hypothesis validation (direct effects).

Hypothesis	Independent Variable	Dependent Variable	β	R^2	p -Value	Conclusion
H_1	Attributes before and during a Green Manufacturing Process	Operating Benefits	0.609	0.371	$p < 0.001$	Accepted
H_2	Attributes before and during a Green Manufacturing Process	Commercial Benefits	0.234	0.150	$p < 0.001$	Accepted
H_3	Operating Benefits	Commercial Benefits	0.677	0.555	$p < 0.001$	Accepted
H_4	Operating Benefits	Economic Benefits	0.475	0.392	$p < 0.001$	Accepted
H_5	Commercial Benefits	Economic Benefits	0.423	0.345	$p < 0.001$	Accepted

Figure 2 shows that the dependent variables have an associated R^2 value as a measure of the variance explained, which is due to one or several independent variables. Table 5 decomposes the R^2 value according to the contribution of each independent variables. In the first column the dependent variables are presented, and the second, third, and fourth present the independent variables; finally, the last column contents the total value of R^2 .

Table 5. R^2 value decomposition.

To	From			R^2
	Operating Benefits	Commercial Benefits	Attributes before and during a Green Manufacturing Process	
Operating Benefits				0.371
Commercial Benefits	0.555			0.150
Economic Benefits	0.392	0.345		0.737

For example, it is observed that the variable *Commercial Benefits* has a total value of $R^2 = 0.705$, which indicates that it is explained in a 70.5% by the variables *Attributes before and during a Green*

Manufacturing Process and Operating Benefits, but only 15.0% comes from the first variable while 55.5% comes from the second variable. In that sense, *Operating Benefits* has a greater explanatory power in the dependent variable (note that the sum of the contributions of each variable is the percentage of variance explained). In the case the variable *Economic Benefits*, which is explained in 73.7%, 39.2% is explained by the variable *Operating Benefits* and 34.5% by the variable *Commercial Benefits*.

Moreover, Table 6 portrays in its first column the type of effect, whether the sum of indirect effects or the total effects between variables. The last column presents the associated *p*-value and the ES as a measure of the explanatory power between the variables. These values were taken from the results obtained once the model was run in the WarpPLS 6.0 Software and are essential to interpret the results in Section 4.

Table 6. Sum of indirect and total effects.

Type Effect	From	To	
Indirect	<i>Attributes before and during a Green Manufacturing Process</i>	<i>Commercial Benefits</i>	0.413 (<i>p</i> < 0.001) ES = 0.265
	<i>Attributes before and during a Green Manufacturing Process</i>	<i>Economic Benefits</i>	0.563 (<i>p</i> < 0.001) ES = 0.310
	<i>Operating Benefits</i>	<i>Economic Benefits</i>	0.286 (<i>p</i> < 0.001) ES = 0.236
Total	<i>Attributes before and during a Green Manufacturing Process</i>	<i>Operating Benefits</i>	0.609 (<i>p</i> < 0.001) ES = 0.371
	<i>Attributes before and during a Green Manufacturing Process</i>	<i>Commercial Benefits</i>	0.647 (<i>p</i> < 0.001) ES = 0.416
	<i>Attributes before and during a Green Manufacturing Process</i>	<i>Economic Benefits</i>	0.563 (<i>p</i> < 0.001) ES = 0.310
	<i>Operating Benefits</i>	<i>Commercial Benefits</i>	0.677 (<i>p</i> < 0.001) ES = 0.555
	<i>Operating Benefits</i>	<i>Economic Benefits</i>	0.761 (<i>p</i> < 0.001) ES = 0.628
	<i>Commercial Benefits</i>	<i>Economic Benefits</i>	0.423 (<i>p</i> < 0.001) ES = 0.345

In addition, the only effect with three segments involves the *Attributes before and during to the Green Manufacturing Process* variable along with the *Economic Benefits* variable through the mediating variables *Operating Benefits* and *Commercial Benefits*, which are the highest and most significant indirect effects, since the *Attributes before and during a Green Manufacturing Process* variable does not have a direct effect on the *Economic Benefits* variable.

Likewise, this indirect effect is expected, since when a company makes the decision to update its traditional manufacturing process and implement a GM process with the use of these attributes, it promotes a series of savings associated with the use and consumption of resources, as well as raw materials, savings in the distribution of supply products and materials, waste reduction, and reprocessing.

It is important to mention that the indirect effect from *Attributes before and during to the Green Manufacturing Process* on *Commercial Benefits*, through the mediating *Operating Benefits* variable is higher than the direct effect that exists between them; this indirect effect is 0.413 while the direct effect is only 0.234, which means that when a company generates *Operating Benefits* and increases the quality in products and processes, companies are indirectly obtaining *Commercial Benefits*, because they are able to provide a better service to clients, which in the long term generates a better reputation and may lead to market expansion.

Similarly, Table 6 displays six total effects, which are statistically significant and indicate the importance of these aspects, as well as the magnitude of the effect that is used in the attributes to obtain operational, commercial, and *Economic Benefits*. This is crucial, since even nowadays it is still questioned if implementing a GM process will automatically bring a benefit, and these findings prove quantitatively and statistically that relationship.

In addition, the total effect of the *Operating Benefits* variable on the *Economic Benefits* variable can be remarked, since the highest total effect indicates that, when obtaining *Operational Benefits*, it is

guaranteed that for any company that implements a GM process, essential *Economic Benefits* may be acquired. As a result, these processes and products have been improved by reducing material waste, production costs, workforce, reprocessing, warranty costs, marketing costs, etc.

In summary, the results presented in Table 6 may help companies have better confidence and initiative for implementing GM practices in their processes—a change that will significantly impact the environment. The data obtained show that companies that make the decision to adapt their traditional processes to GM processes will obtain a substantial series of operational, commercial, and *Economic Benefits*.

4.4. Sensitivity Analysis

Table 7 illustrates the sensitivity analysis from the relationships between the latent variables in the model when they have high and low levels independently, as well as a combination of levels (four stages for each relationship or hypothesis). In the first column (named "To") the dependent variables are presented; the second one presents the levels that can have the latent variables; the third column includes the value of P (i) (probability of occurrence in its high and low level of each of the latent variables); the other columns present the values of the probabilities of occurrence simultaneously in each scenario.

Table 7. Sensitivity analysis.

From		Attributes before and during a Green Manufacturing Process		Operating Benefits		Commercial Benefits	
		To	Level	P (i)	+	-	+
<i>Operating Benefits</i>	+	<i>Operating Benefits</i>	0.156	& 0.086 If 0.485	& 0.007 If 0.040		
			0.150	& 0.007 If 0.040	& 0.075 If 0.416		
<i>Commercial Benefits</i>	+	<i>Commercial Benefits</i>	0.186	& 0.100 If 0.566	& 0.004 If 0.020	& 0.091 If 0.586	& 0.000 If 0.000
			0.165	& 0.004 If 0.020	& 0.088 If 0.485	& 0.002 If 0.011	& 0.114 If 0.762
<i>Economic Benefits</i>	+	<i>Economic Benefits</i>	0.161			& 0.081 If 0.517	& 0.000 If 0.00
			0.159			& 0.000 If 0.000	& 0.095 If 0.510 & 0.125 If 0.000 & 0.000 If 0.000 & 0.122 If 0.739

For example, it is observed that the probability that *Operating Benefits* are present independently at their low level is 0.156, while at their high level is 0.150. However, the probability of being at a high level simultaneously with the *Commercial Benefits* is only 0.091, but the conditional probability of having these *Commercial Benefits* at a high level due to high *Operating Benefits* is 0.586, which indicates that managers must focus on obtaining the second type of benefits, since there is a high probability of obtaining the first ones.

However, if there are simultaneously *Operating Benefits* and *Commercial Benefits* at their low levels, the probability of the two variables occurring together is only 0.114; therefore, the importance of the analysis becomes significant when analyzing the probability of occurrence for the first variable at its low level, since the second variable has occurred at that same level, because the probability of that event is 0.762. That information indicates that if a manager does not strive to achieve *Operating Benefits* with the GM implementation process, there is a high probability that *Commercial Benefits* will not be achieved.

The previous conclusion is verified when the *Operating Benefits* have a high level and the *Commercial Benefits* a low level, where it is observed that the probability of occurrence for that event

simultaneously is only 0.002, which indicates that whenever the first benefits are obtained, the second variable will be present in that low scenario. As a result, the probability that the second variable occurs at its low level and the first at its high level is only 0.011—a very low probability, which indicates that *Operating Benefits* are always associated with *Commercial Benefits*.

5. Practical and Theoretical Implications

5.1. Theoretical Implications

The analysis shows that it is possible to acquire favorable results for the company when implementing GM, since it is possible to improve the use of resources, energy, and raw material, and therefore the environmental impact is reduced. On the other hand, the information presented in this research has great relevance as a GM evaluation or implementation tool, and allows for obtaining the following conclusions:

The variable *Attributes before and during a Green Manufacturing Process* and its items show their importance in GM, which can be verified as in Table 2. In addition, this relationship indicates that each GM process must have certain attributes, such as reduction of emissions and waste, preservation of natural resources, clean production, generation of green products, use of green technologies, and selection of green suppliers, as mentioned in Wang, Huscroft, Hazen and Zhang [21].

Furthermore, these attributes and their execution generate a series of *Operating Benefits* in the productive processes, which is validated statistically with H_1 , since it has a direct, positive, and significant effect. Moreover, it indicates that when GM process is implemented, operational benefits will be generated in terms of competition, productivity, and efficiency [45]. According to the previous information, it is observed that a series of *Commercial Benefits* are obtained, a statement that is validated with H_2 and H_3 ; consequently, there is a direct, positive, and significant effect between those three latent variables. In addition, when implementing a GM process, there will be a better production process and better products, which will lead to new potential customers, market expansion, and a better reputation with clients and competitors [48].

Although the *Attributes before and during a Green Manufacturing Process* variable does not have a direct effect on the *Economic Benefits* variable (it has not been studied in this research), this variable does have a significant indirect effect. This fact is not surprising, since having a GM process in a company generates a series of *Economic Benefits* associated with the reduction of resources, supplies, and raw materials consumption, which agree with Roy and Khastagir [42]. In addition, the fact of having a green image, better quality, better customer service, and higher certifications will attract new customers, increasing sales and financial gains, as Sun, Miao and Yang [11] mention.

Furthermore, it is also relevant to review the direct, positive, and significant relationship that exists between operating, commercial, and *Economic Benefits*, which are validated through H_4 and H_5 , confirming that, if a GM process is implemented with the use of attributes, benefits will be generated in terms of the processes, products, reputation, quality of the final product, and customer service, which, consequently, will be reflected in the savings, profits, and commercialization of the company.

Today, it is essential to emphasize that not having a GM process may place a company in a positive or negative situation, classifying it as obsolete. In addition, the GM is a valuable tool to promote the environmental awareness of clients, customers, suppliers, and manufacturers.

Finally, this research can be applied in different types of manufacturing as a new way to evaluate whether their manufacturing processes are green, with the use of the attributes mentioned in this work. Furthermore, using these attributes guarantees the obtaining of several operational, commercial, and *Economic Benefits* in the organization.

5.2. Practical Implications

It is important to emphasize that, although the research was carried out in the Mexican maquiladora industry context, it can also be applied in other countries with emerging economies

that have similar conditions. Also, the results allow companies to recommend that maquiladoras develop green products and processes through proactive environmental management policies and environmental practices, which guarantees new green markets and customers who are more committed to their environment and its preservation.

From the data analysis in Table 7, the following conclusions and industrial inferences can be established for companies that implement GM in their production processes:

- The GM implementation is a continuous process that must be monitored throughout the production system; there are attributes that must be evaluated before and during the production process.
- The execution of activities that provide the *Attributes before and during a Green Manufacturing Process* helps to obtain *Operating Benefits*, since there is a probability that this will occur of 0.485 and *Commercial Benefits* with a probability of 0.566 to happen. In addition, the previous information indicates that managers must have a tracking system for GM practices in order to have control of them and make the necessary adjustments and guarantee the desired benefits, especially those of an operational type, since the commercial and economic benefits depend on them. Also, in the event of low levels of execution of the activities associated with the obtained attributes that characterize the GM process, there is also a risk of having low *Operating Benefits* (probability of 0.416) and *Commercial Benefits* (probability of 0.485).
- *Operating Benefits* at a high level guarantee the obtaining of high *Commercial Benefits* (probability of 0.586); therefore, the way that it is implemented should be a priority for managers when implementing GM. However, if these operating benefits are low for any reason, the risk of obtaining low *Commercial Benefits* is 0.762; if there is a very high value, since the implementation is associated with aspects related to the product quality and cost, it means these are not attractive to the customer, so the company loses market opportunities.
- According to the previous information, it is concluded that high levels of *Operating Benefits* bring *Commercial Benefits*, and these in turn bring *Economic Benefits*. In fact, it can be observed that it is not possible to have high economic benefits when there are low *Operating Benefits*, which again indicates that managers should focus on aspects associated with the cost, quality, and company image. Moreover, there is a high risk of having financial problems when *Operating Benefits* are not obtained, since when they have low levels, there is a high risk that the *Economic Benefits* are low (probability of 0.833).
- Companies must guarantee *Commercial Benefits* at high levels in order to obtain *Economic Benefits* at that same level (probability of 0.510), since, if there are low levels for the first variable, there is a high risk of also having low levels in *Economic Benefits* (probability 0.739).

5.3. Future Studies

The evaluation of a GM should also consider attributes after the manufacturing process since, in this study, only the attributes before and during the manufacturing process have been considered. In future studies, how the attributes would be related after the manufacturing process will be considered, by integrating them into the model proposed in this research or associating the three different types of attributes and knowing their relationship quantitatively by structural equation modeling. Likewise, the social benefits or some other possible type of benefits that can be obtained with the update of the traditional manufacturing process to a GM process could be associated.

6. Conclusions

Evaluating the performance of green production processes will continue to be of interest to academia and industry, which are committed to the environment in which they and their clients perform. Therefore, the identification of green attributes before and during the production process will

be an indication of the level of implementation of GM processes and the possible benefits that will be obtained. The analysis of the attributes and benefits of GM processes leads to the following conclusions:

1. The monitoring of green attributes before and during the production process allows us to evaluate the company's GM process and facilitates the obtaining of operational benefits in the production line and commercial benefits to clients.
2. The operational benefits obtained from implementing a GM process help to improve the commercial and economic benefits to the companies.
3. *Commercial Benefits* obtained by implementing GM facilitate the increase of economic benefits for companies.

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Appendix A. Latent variables validation

Confidence level used: 95%

Value for two-tailed tests: 1.960

Table A1. Z ratios for loadings.

Items	Operating Benefits	Commercial Benefits	Economic Benefits	ABP and ADP
Increase in the quality of their processes	21,569			
Product design improvement	21,509			
Increase in its technological innovation	20,976			
Optimization in the use of available resources	21,521			
Low product rework	21,465			
Greater competitiveness, productivity, and efficiency	22,469			
Increase in the quality of the final product	21,682			
Local market expansion		22,164		
Better customer service		21,920		
Increase in the number of products classified as green		22,032		
Greater environmental certifications		21,925		
Increase in sales			21,939	
Increase in economic gains			22,382	
Reduction of marketing costs			22,799	
Reduction of material waste			22,192	
Reduction of production costs			22,711	
Reduction of workforce for reprocessing			22,512	
Cost reduction for guarantees			22,318	
Attributes before the process				24,866
Attributes during the process				24,866

Table A2. Confidence intervals for loadings (Low and Up).

Items	<i>Operating Benefits</i>	<i>Commercial Benefits</i>	<i>Economic Benefits</i>	<i>ABP and ADP</i>
Increase in the quality of their processes	0.754	0.905		
Product design improvement	0.752	0.903		
Increase in its technological innovation	0.733	0.884		
Optimization in the use of available resources	0.752	0.903		
Low product rework	0.750	0.901		
Greater competitiveness, productivity, and efficiency	0.786	0.936		
Increase in the quality of the final product	0.758	0.909		
Local market expansion		0.775	0.925	
Better customer service		0.766	0.917	
Increase in the number of products classified as green		0.770	0.921	
Greater environmental certifications		0.767	0.917	
Increase in sales			0.767	0.918
Increase in economic gains			0.783	0.933
Reduction of marketing costs			0.797	0.947
Reduction of material waste			0.776	0.926
Reduction of production costs			0.794	0.944
Reduction of workforce for reprocessing			0.787	0.937
Cost reduction for guarantees			0.780	0.931
Attributes before the process				0.869 1.018
Attributes during the process				0.869 1.018

Appendix B. Z ratios and confidence intervals for β **Table A3.** Z ratios for β values.

Latent variables	<i>Operating Benefits</i>	<i>Commercial Benefits</i>	<i>ABP and ADP</i>
<i>Operating Benefits</i>			15.45
<i>Commercial Benefits</i>	17.315		5.681
<i>Economic Benefits</i>	11.86	10.491	

Table A4. Confidence intervals for β values (Low and Up).

Latent variables	<i>Operating Benefits</i>	<i>Commercial Benefits</i>	<i>ABP and ADP</i>
<i>Operating Benefits</i>			0.532 0.687
<i>Commercial Benefits</i>	0.601	0.754	0.153 0.315
<i>Economic Benefits</i>	0.396	0.553	0.344 0.502

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