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Design, process and commercial benefits gained from AMT

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Abstract

Purpose – The purpose of this paper is to measure the relationships between advanced manufacturing technologies (AMTs) categories (stand-alone, intermediated and integrated systems) implementation and design, process and commercial benefits obtained.

Design/methodology/approach – A survey is designed with benefits gained from AMT implementation as well as its categories, which is applied to the maquiladora industry. A structural equation model with data from 383 responses is used to measure the relationship between AMT categories and benefits gained using nine hypotheses that are tested statistically significant using partial least squares. Also, using conditional probabilities, a sensitivity analysis reports how low and high levels from AMT implementation influence on the obtained benefits.

Findings – Integrated systems are the most important AMT for maquiladoras and have the strongest impact on design, processes and commercial benefits.

Research limitations/implications – Data obtained support the model, but results may be different in another industrial sector and countries with different labor culture and technological level.

Practical implications – Managers in maquiladora industry must focus their attention on integrated manufacturing systems, because high implementation levels guarantee the biggest probability to gain benefits in design, production process and commercial.

Originality/value – The relationship between AMT and their benefits has not been measured in depth, and this paper contributes to understand that problem. In addition, this paper is the first to report a sensitivity analysis that enables managers to acknowledge the probability of obtaining certain benefits.

Keywords Performance measurement, Statistical analysis, Manufacturing performance, Advanced manufacturing technology, Manufacturing industry

Paper type Research paper

1. Introduction

Maquiladora companies, also known as "shared production plants" or "twin plants," emerged as a new manufacturing operation model, which are mostly located in the Mexico–US border (Munguia *et al.*, 2018). Generally, maquiladoras are foreign-owned companies that temporarily import equipment and raw materials, which are later processed and assembled in Mexico in order to be then exported overseas under preferential tariff programs (Hadjimarcou *et al.*, 2013). Also, maquiladoras take advantage of qualified and inexpensive workforce, different labor laws, and preferential union policies in host countries.

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The maquiladora program is a success story of Mexico's export-led industrialization model. Thanks to the North America Free Trade Agreement, signed in 1994, maquiladoras have boomed around the country (Carrillo and Zárate, 2009) and brought over a variety of updated industrial processes and technologies, such as advanced manufacturing technologies (AMT) (García-Alcaraz *et al.*, 2015). Currently, according to the Mexican National Institute of Statistics and Geography, in March 2019, there are 5,115 maquiladoras in Mexico (INEGI, 2019). Specifically, in the north of Mexico, where there are the most manufacturing cities; there are 1,421 maquiladoras (27.78 percent), 329 facilities out of 505 from the Chihuahua State are established only in Ciudad Juarez. Also, that maquiladora sector employs 305,313 people in this city. In fact, the maquiladora industry is a direct source of foreign investment; in 2018 in the Chihuahua State, that investment was $1,138m, where the principal investors were the USA with 71.6 percent, Canada with 9.6 percent, the UK with 7.5 percent and Spain with 7.2 percent.

Nowadays, the maquiladora program is Mexico's engine for global commercial competition (Pandza *et al.*, 2005; Utar and Ruiz, 2013), which has led company managers to prioritize and pay close attention to both innovation and emerging industrial paradigms. In this sense, many organizations have adopted AMTs as a tool for gaining a competitive advantage in globalized markets (Birasnav and Bienstock, 2019).

AMTs are associated with electronic, mechanical and computer systems used to operate and manage production (Nath and Sarkar, 2017). They encompass a range of programmable machines that operate, monitor and comprise a production process. AMTs also involve computer-aided manufacturing, flexible manufacturing systems, numerical control machines (Lewis and Boyer, 2002), robotics, bar codes and other automatic identification techniques (Percival and Cozzarin, 2010). Finally, AMT can be grouped in three categories: isolated systems, intermediated systems and integrated systems (Small and Chen, 1997).

The wide range of AMT forces managers to carefully analyze their choices before deciding. Prior to implement AMTs, it is important to know what types of improvements are necessary, how they are linked to the company's overall production strategy and to what extent both product design and manufacturing are either integrated or isolated from each other (Swink and Nair, 2007). The AMT implementation brings major attractive benefits, including greater product and volume flexibility, higher quality, fewer costs and better process control (Waldeck and Leffakis, 2007). Moreover, it minimizes production costs, improves performance, helps corporations develop a solid competitive advantage (Ocampo *et al.*, 2017), increases manufacturing capacity and improves production and delivery parameters (Koc and Bozdag, 2009). Finally, AMTs have a positive impact on process flexibility, since they are programmable, they can help companies increase product range in small volumes by replacing software instead of hardware (Bai and Sarkis, 2017).

Since AMTs improve both performance and cost effectiveness, their proper management and investment are key tasks in maquiladoras, especially in regions where high-technology products are manufactured (Cheng *et al.*, 2018). Also, AMTs demand corporations to adjust their organizational and cultural structures to their requirements (Salehan *et al.*, 2018). Such changes are essential, since the purpose of investing in AMT is to obtain long-term benefits, otherwise any AMT implementation proposal would be erroneous. The process of introducing AMTs in a production system triggers numerous changes in an organizational structure, a production process or a plant's layout, which implies that obstacles are likely to arise (Cardoso *et al.*, 2012). The most common problems in the AMT implementation phase may be associated with machine maintenance, installation and configuration, supplier relationships, decision making or a lack of prior knowledge, among others (García and Alvarado, 2013).

Capitalizing new AMTs also involves experiencing technological and organizational transformations, since maquiladoras adjust their operational strategies to the advantages of their machinery, focusing on aspects, such as quality, flexibility and timely deliveries, while also ensuring alignment with their headquarters (Ocampo *et al.*, 2017).

In order to select the most appropriate AMTs, it is important to take into account the resources that are available, as well as evaluate the corporation goals to ensure that the benefits of these technologies are maximized (Bourke and Roper, 2016). In Mexico, the AMT implementation efforts are abruptly ended when managers are not aware of the benefits of investing on new production technology (García and Alvarado, 2013), or when they are not informed about the organizational changes that must be undergone, especially in terms of employee training, empowerment and technology management (Cardoso *et al.*, 2012). Nowadays, a variety of studies describe the evolutionary process of manufacturing companies in countries, such as Mexico and China (Sargent and Matthews, 2009), highlight the best AMT implementation practices (Carrillo and Zárate, 2009), or emphasize on the benefits from these technologies in the production process (Ocampo *et al.*, 2017). However, the literature review has not found the relationship between the AMT implementation practices with their corresponding benefits yet. It is assumed that the higher the technological level, the greater the benefits for the company, and the lower the technological level, less benefits will be obtained. Therefore, the main question that managers ask themselves is: how does each of these types of technologies contribute to the company? What type of technology should efforts and resources from the company must be focus on?

Furthermore, this paper is aimed to address that gap and seek to find which benefits are particularly obtained from the implementation of AMTs in the maquiladora industry, where a structural equation model (SEM) is developed to measure and quantify the relationship between three types of AMTs (i.e. stand-alone systems, integrated systems and intermediate systems) with three types of benefits: design benefits, process benefits and commercial benefits. In addition, AMTs are considered as independent latent variables, whereas AMT benefits are described as dependent latent variables or responses. All the latent variables are related through nine research hypotheses.

Findings in the present research may be useful for managers who are interested on the best AMT for their companies, having specific corporation goals as well. Moreover, this research reports a sensitivity analysis to support companies along their decision-making processes, which is based on conditional probabilities to determine how both low and high levels of AMT implementation either hinder or promote design benefits, process benefits and commercial benefits. In this sense, the analysis may help identify possible risks in the AMT implementation process as well as take the necessary corrective actions.

The remainder of this paper is structured as follows: in Section 2 appears a literature review that justifies the research hypotheses, whereas Section 3 detailed the research materials and methods. Then, in Section 4 the results are displayed, Section 5 discusses the main findings from both the SEM and the sensitivity analysis, and finally, Section 6 presents the conclusions and the industrial implications of the study.

2. Literature review and hypotheses

Table I illustrates a taxonomy proposed by Small and Chen (1997) and the main benefits gained after a successful implementation process, as well as authors reporting their industrial usage and support. Those categories of AMT and benefits represent latent variables in this study that appear in first column and the items or observed variables are displayed in the second column with an acronym. The following paragraphs describe them, as well as report a list of authors that support their implementation.

Category of AMT or benefit	Types of AMT and benefits
Stand-alone systems	SAS1: computer-aided design (CAD)
	SAS2: computer-aided process planning (CAPP)
	SAS3: NC/CNC or DNC machines
	SAS4: machines working with laser (MWL)
	SAS5: lifting robots
	SAS6: other robots
Intermediate systems	INS1: automated storage and retrieval systems (AS/RS)
	INS2: automated material handling systems (AMHS)
	INS3: automated inspection and test equipment (AITE)
Integrated systems	ISY1: flexible manufacturing cells or systems (FMC/FMS)
	ISY2: computer-integrated manufacturing (CIM)
	ISY3: just in time (JIT)
	ISY4: material requirements planning (MRP)
	ISY5: manufacturing resource planning (MRP II)
Design benefits	DEB1: design time reduction
	DEB2: quality in design
	DEB3: reduced lead-time from product design
Process benefits	PRB1: less machinery
	PRB2: reduced lot size
	PRB3: machine flexibility
	PRB4: process flexibility
	PRB5: volume flexibility
	PRB6: expansion flexibility
	PRB7: reduced waste and rework
Commercial benefits	COB1: helps to keep up with competitors
	COB2: prompt response to customer needs
	COB3: early market entry
	COB4: shorter delivery times
	COB5: increased sales

Table I.
AMT categories

Stand-alone systems

Stand-alone systems lie at the lowest level of the AMT taxonomy. As they are moving from Level 1 to 3, the degree of interaction increases; therefore, stand-alone systems are known to require minimal or no interaction at all with other technologies. As Table I indicates, there are six types of stand-alone systems.

Even though stand-alone systems are isolated technologies, their applications are vastly reported in the literature. In their work, Dubovska *et al.* (2014) addressed the application of CATIA, a computer-aided design (CAD) software program for virtual simulation of industrial turning, and milling processes. Similarly, Alghazzawi (2016) discussed the many possible applications of CAD/CAM technology, whereas Mikolajczyk *et al.* (2018) discussed the use of CAD/CAM technology for a wire cutting system. In an attempt to integrate multiple stand-alone systems, Xie *et al.* (2000) conducted a case study in which CAD, computer-aided process planning (CAPP) and CAM are combined in an industrial metal cutting system, while Grabowik *et al.* (2005) reported the implementation of CAD, CAPP and PPC (production planning and control) all together.

In addition, Milosevic *et al.* (2017) developed an advanced system – named e-CAPP – for distributed and collaborative environment for assisting manufacturing companies in part manufacturing processes. As for computer numerical control (CNC) machines, Jayakrishna *et al.* (2016) performed a comparative analysis of a sustainable process and a conventional process using CNC. Meanwhile, Sang and Xu (2017) developed an advanced could-based CNC system, consequently, demonstrating the evolution of this type of technology. Finally, regarding industrial robots, their applications have been reported in both hearing aid manufacturing (Walker *et al.*, 2019) and sustainable manufacturing contexts (Ogbemhe *et al.*, 2017).

Benefits from stand-alone systems

Investing in stand-alone systems must be redeemable, otherwise the implementation is not justifiable. Several authors discuss attractive benefits from implementing this type of AMT. For instance, Zhang and Zhou (2019) claim that implementing CAD techniques automatically leads to companies planning actions for recycling product components and expanding their lifecycle. Also, Zhang *et al.* (2019) argue that CAD systems have the ability to streamline design processes and increase process quality, whereas Geromin *et al.* (2018) state that CAD systems allow companies to rapidly gain a significant amount of design-related knowledge on a regular basis. As for industrial robots, they can safely and easily perform tasks that are originally too dangerous for a human to perform. Following this discussion on the benefits from stand-alone systems in manufacturing, the first research hypothesis can be proposed as follows:

H1. Stand-alone systems implemented in a production system have a positive direct effect on design benefits.

CAPP systems facilitate production process planning and can monitor tasks and materials along the production lines, which, in turn, allows companies to observe real-time status updates of product orders (Zhang and Bernard, 2018). Since CAPP technologies are automated and can be multitasked, they minimize the number of tasks that are required in a production system to attain a certain production capacity (Swink and Nair, 2007). Also, CNC machines can be programmed to adapt themselves to new tasks, thereby increasing flexibility in the production process and reducing setup times. Finally, industrial robots are nowadays highly accurate, therefore they may help minimize both waste and rework, as a result, increase the product quality (Koc and Bozdag, 2009). Following this discussion, the second research hypothesis can be proposed below:

H2. Stand-alone systems implemented in production systems have a positive and direct effect on process benefits.

Stand-alone systems contribute to the commercial success: they ensure low-cost production efficiency, they are accurate, and increase both product reliability and quality (López de Lacalle and Lamikiz, 2009). For instance, the effective implementation of CAD/CAM systems reduces design costs, product cycle time and setup times, helping companies penetrate markets early, as well as improving delivery times (Zhang *et al.*, 2019). Furthermore, due to their flexibility, CNC systems increase production agility and help organizations quickly meet ever-changing customers' needs, thereby increasing customers' satisfaction. According to this discussion, the third research hypothesis can be proposed as follows:

H3. Stand-alone systems implemented in production system have a positive and direct effect on commercial benefits.

Intermediate systems

Intermediate manufacturing technologies are combined with other technologies through particular protocols or communication interfaces, which support tasks, such as material handling, storage and inspection. Three types of intermediate systems are considered in this research: automated storage and retrieval systems (AS/RS), automated material handling systems (AMHS) and automated inspection and test equipment (AITE).

Intermediate systems are a key component from manufacturing systems; they are implemented at the assembling stage and their automation is particularly beneficial to both product lifecycle and productivity (Choe *et al.*, 2015). Also, their applications are reported multiple times in the literature review. For instance, Bruno and D'Antonio (2018) proposed the reconfiguration of a warehousing system using an autonomous vehicle storage and retrieval system (AVS/RS), whereas Manzini *et al.* (2016) proposed a series of models to optimize deep-lane unit-load AVS/RS. Similarly, in their work, Lin *et al.* (2013) employed a dynamic vehicle allocation control approach for AMHS in the semiconductor manufacturing industry.

Benefits from intermediate systems

The advantages of implementing intermediate systems in manufacturing processes are numerous (Bourke and Roper, 2016). First, AS/RS are considered as a key storage tool in distribution centers and automated production environments (Ouhoud *et al.*, 2016). Currently, there are multiple types of AS/RS, including unit-load, mini-load and flow-rack systems (Hachemi *et al.*, 2012). These technologies, along with their outstanding capabilities for material handling, enable to design new and increasingly sophisticated products, which complex components probably could not be manufactured without AS/RS (Walker *et al.*, 2018). Moreover, the probability of damaging either raw materials or products is low when AS/RS are implemented, since these systems are highly precise (Halim *et al.*, 2015). In order to contribute to this discussion; the fourth research hypothesis is presented below:

H4. Intermediate systems implemented in production processes have a positive and direct effect on design benefits.

Automated production, especially automated material handling, has increased both production process flexibility and safety (Harisha *et al.*, 2014). If it is compared to traditional storage systems, AR/RS improve space utilization, reduce the number of machines that are necessary in a production process and improve both inventory management and production safety (Ghomri and Sari, 2017). Nowadays, material handling is a formal research field in manufacturing that seeks to ensure the orderly, timely and safe handling of raw materials, from and to the right place, and in the right quantity, while simultaneously optimizing workforce, reducing waste and eliminating rework (Fellows, 2017). As a matter of fact, this may be the most important operating benefit that companies seek to gain as a result of implementing intermediate systems. Therefore, the fifth research hypothesis is proposed:

H5. Intermediate systems implemented in production processes have a positive and direct effect on process benefits.

AS/RS in manufacturing improve not only inventory management and storage capacity, but also reliability, cost efficiency and inventory visibility along the entire production line. In turn, these advantages allow manufacturers to minimize delivery times (Nativ *et al.*, 2016) as a result, customers' satisfaction levels and sales increase (Brezovnik *et al.*, 2015). Moreover, AS/RS can handle pallets without being operator-manipulated; therefore, the process is entirely automated and products preserve their quality features (Roodbergen and Vis, 2009). Consequently, companies gain fundamental competitive and commercial advantages. Based on this discussion, the sixth research hypothesis can be presented below:

H6. Intermediate systems implemented in production processes have a positive and direct effect on commercial benefits.

Integrated systems

Integrated manufacturing technologies are highly interconnected and can be categorized as either integrated process technologies – such as computer-integrated manufacturing (CIM) and flexible manufacturing – or integrated information logistic technologies, including just in time (JIT) and manufacturing resource planning (MRP II) (Small and Chen, 1995; Kotha and Swamidass, 2000; Percival and Cozzarin, 2010; Beaumont *et al.*, 2002). The use of integrated systems is not contemporary, but it is not mature enough yet. Many communication protocols are still being developed as an attempt to fully integrate these technologies (Umar *et al.*, 1991), which applications are widely reported in the literature review (Wang, 2018). A recent implementation of CIM is proposed by Delaram and Fatahi Valilai (2018), whereas JIT and TQM applications can be consulted in Iqbal *et al.* (2018). Finally, Wang *et al.* (2017) proposed integrating MRP with JIT for material handling processes.

Benefits from integrated systems

Integrated manufacturing technologies require considerable economic investments, which results take too much time to be seen. CIM systems are implemented in manufacturing processes to integrate all production technologies along with their benefits, which, in turn, have resulted in a variety of production systems (Choi and Lee, 2001) that comprise from product design tasks to distribution activities. Nowadays, some technologies rely first on the CAM concept for product design; then, on CAPP for the production process, all this while simultaneously adopting a JIT philosophy (Mikolajczyk *et al.*, 2018). As for flexible manufacturing cells or systems (FMC/FMS), they are mostly applied on concurrent engineering, thus helping companies quickly make changes in product design and decrease delivery times. As a result, companies are ensured an early market entry. Finally, MRP systems help properly plan and calculate the materials and components needed to manufacture a product, as well as enable companies to reduce product development cycle times, since products are rapidly conceptualized, designed and manufactured. From this perspective, the seventh research hypothesis is stated as follows:

H7. Integrated systems implemented in production processes have a positive and direct effect on design benefits.

Integrated systems reduce the number of machines required in a production process. In addition, since they are highly technical systems and can be easily programmed, they are applied on both flexibility and quality without increasing costs (Gunasekaran and Thevarajah, 1999). In fact, FMS are particularly useful to increase flexibility in aspects, such as product volume and product expansion. Integrated technologies are also remarkably accurate as they help reduce production process errors and the rate of defective parts (Mahmood *et al.*, 2017). On the other hand, MRP systems make in-process inventory management tasks more flexible by enabling companies to trace and visualize the production process in real time, which helps timely detect production process errors, including defective and missing parts (Wang *et al.*, 2017). Finally, regarding JIT manufacturing, authors, such as García-Alcaraz *et al.* (2016), have managed to identify the benefits of this philosophy, including quality and flexibility, to name a few. In order to contribute to this discussion about the benefits of integrated systems, the eighth research hypothesis is declared below:

H8. Integrated systems implemented in production processes have a positive and direct effect on process benefits.

If they are properly implemented, integrated systems may offer attractive commercial benefits for the manufacturing industry. They help maintain the corporation competitiveness and promote the evolution to Industry 4.0 (Demi and Haddara, 2018). For example, MRP systems have evolved to enterprise resource planning (ERP) systems, therefore, integrating suppliers' needs as well as customers' needs with the aim of reducing response time and increasing product quality (Ranjan *et al.*, 2016). ERP systems may also help decrease material handling and storage costs, since JIT reduces cycle times and inventory levels, and increases the rate of timely and orderly deliveries (Wang *et al.*, 2017). As a result, customers' satisfaction increases, and companies maintain their position in the market. Following this discussion, the ninth research hypothesis can be proposed below:

H9. Integrated systems implemented in production processes have a positive and direct effect on commercial benefits.

Figure 1 illustrates the nine hypotheses graphically.

3. Methodology

Questionnaire design

In order to test the SEM displayed in Figure 1, data from the maquiladora industry are collected through a questionnaire designed considering the Small and Chen (1995) classification of AMT, and a list of 36 AMT benefits, which are classified in six groups: design, commercial, production, process, materials and human resources. Then, 26 implementation problems related to the three AMT implementation stages: selection, installation and operation. This paper only analyzes the relationships between the three AMT categories with three types of benefits: design, process and commercial.

The questionnaire comprises four sections. The first section is focused on gathering demographic data from the sample; the second section explores the level of implementation of AMT in the maquiladora industry; the third section seeks to collect information about AMT benefits, whereas the last section aims to identify the main barriers for the AMT implementation. The second and third sections of the questionnaire had to be answered using a five-point Likert scale, which lowest value (i.e. 1) implied that the level of AMT implementation is low, or an AMT benefit is not obtained. On the other hand, the higher value of the scale (i.e. 5) implied that the level of AMT implementation is high, or an AMT benefit is always obtained. Values such as 2, 3 and 4 are intermediate values. For further information about the questionnaire, please consult the supplementary material.

Questionnaire administration

The questionnaire is administered in the Mexican maquiladora industry, specifically in the city of Ciudad Juárez. The sample comprised managers, supervisors and production/manufacturing engineers with at least two years of experience in their job positions. First, the

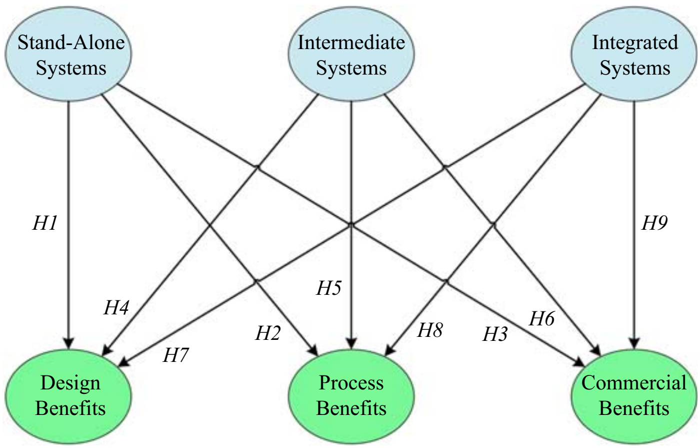

Figure 1.
Proposed model

stratified sampling method is followed, and then, it is adopted the snowball sampling technique. The questionnaire is applied individually through a face-to-face interview with each participant to guarantee that they really are the employees who occupy the managerial position required for this research, as well as to guide the interview in case of any misunderstanding with questions or items. In order to schedule an appointment with each participant, information provided by the Maquiladora Society of Ciudad Juárez is used (AMAC, by its Spanish acronym).

Data registration and screening

The data collected from the questionnaires are registered in a SPSS 24® database, which is then screened as follows (Hair *et al.*, 2013):

(1) The standard deviation value is estimated for each interview to identify uncommitted responses. Questionnaires with a standard deviation value lower than 0.50 are not considered in the analysis, because it indicates that assessments are similar.

(2) Missing values are identified according to Crambes and Henchiri (2019); if a questionnaire has less than 10 percent of missing values, it can be replaced by the median value. On the other hand, if there are more than 10 percent of missing values, that case is not considered in the analysis. Gaskin (2016b) indicates that missing values can generate problems of bias (Gaskin, 2016a) as it will distort the results (Kock, 2017).

(3) Extreme values or outliers are identified by standardizing item values in each questionnaire according to Hoffman (2019) rules; if absolute standardized values are higher than 4, they are replaced by the median value to avoid bias results.

Latent variable validation

The model showed in Figure 1 integrates six latent variables, which must be validated before their integration into the model. In order to validate these variables, the five coefficients listed in Table II are estimated (Kock, 2018) and in supplementary material section, readers can consult the following information:

- item cross-loadings, 95% confidence intervals and *Z* ratios estimated for each latent variable to ensure convergent validity;
- the correlations among latent variables estimated using the square root of AVE for discriminant validity; and
- additional reliability coefficients for latent variables, including Dijkstra's PLSc reliability coefficient, the true composite reliability coefficient and the factor reliability coefficient.

Test	Coefficient	Acceptable value(s)
Parametric predictive validity	R^2 and Adj. R^2	$\geqslant 0.2$
Non-parametric predictive validity	Q^2	$\geqslant 0$ and similar to corresponding R^2 values
Internal validity	Cronbach's α and internal consistency index	$\geqslant 0.7$
Convergent validity	Average variance extracted (AVE)	$\geqslant 0.5$
Collinearity	Variance inflation factor (VIF)	< 5; ideally <3.3

Table II.
Coefficients for latent variable validation

Structural equation model

The SEM is tested using the partial least squares method on the WarpPLS 6® software, which is widely used to test and estimate causal relationships between latent variables (Hoe, 2008), as it is recommended when data are ordinal, or when it does not have a normality and there are small samples. SEM comprises statistic techniques, such as factor analysis, multiple correlations and path analysis. Moreover, it allows latent variables to have multiple roles (Hair *et al.*, 2010). Modern applications of the SEM technique can be consulted in García *et al.* (2014) and Avelar-Sosa *et al.* (2014), where the main focuses are, respectively, to relate JIT implementation with its benefits, and supply chain risks with the supply chain performance.

Before the model interpretation, some model fit and quality indexes are estimated which appear in Table III. As supplementary resources, also five other indexes are estimated: standardized root mean squared residual, standardized mean absolute residual, standardized χ^2, standardized threshold difference count ratio and standardized threshold difference sum ratio.

SEM effects

Three types of effects can be estimated in SEM; direct, indirect and total effects. Direct effects represent the causal relationships between two latent variables and help validate the research hypotheses. Each direct effect is associated with both a β value, as a regression coefficient, and a p-value, as an indicator of statistical significance. Namely, the H_0: $\beta = 0$ is tested against the alternative and *H1*: $\beta \neq 0$ at a 95% confidence level. Therefore, a relationship between two latent variables is statistically significant when $\beta \neq 0$.

Furthermore, indirect effects measure how a latent variable depends on another variable through a mediator. However, the proposed model does not have this kind of effects. Finally, the total effects represent the sum of direct and indirect effect, and in this report, direct effects and total effects are equal, since there are no indirect effects. In addition, the R^2 value is decomposed in each dependent latent variable to determine the percentage of variance that is explained by the independent latent variable(s) involved in a relationship. This percentage of explained variance is known as size effect (SE). As supplementary material, readers can consult the estimations of the Z ratios for path coefficients (β values) as well as their corresponding confidence intervals.

Sensitivity analysis

A sensitivity analysis is conducted to estimate both the probabilities for the latent variables to occur independently from one another, and the conditional probabilities for each hypothesis. Low and high AMT implementation levels are estimated and attempt to determine how these levels are either enablers of or barriers for AMT benefits. In fact, mathematically speaking, the following analyses are performed:

- The probabilities of finding each latent variable isolated at both its highest-level $P(Z > 1)$ and lowest level $P(Z < -1)$, where $Z > 1$ denotes a high scenario and $Z < -1$ denotes a low scenario.

Index	Acceptable value
Average path coefficient (APC)	$p < 0.05$
Average R^2 (ARS) and average adjusted R^2 (AARS)	$p < 0.05$
Average block VIF (AVIF)	Acceptable if $\leqslant 5$, ideally $\leqslant 3.3$
Average full collinearity VIF (AFVIF)	Acceptable if $\leqslant 5$, ideally $\leqslant 3.3$
Tenenhaus GoF (GoF)	$\geqslant 0.36$

Table III. Model efficiency indices

- The probability of finding two latent variables (one dependent and the other independent) either conjointly or conditionally. In the conjoint analysis, combinations included $P(Z_d > 1)$ and $P(Z_i > 1)$; $P(Z_d > 1)$ and $P(Z_i < -1)$; $P(Z_d < 1)$ and $P(Z_i > 1)$; and $P(Z_d < -1)$ and $P(Z_i < -1)$, which are represented by *&*. On the other hand, in the conditional analysis, the combinations are represented by *if* and included $P(Z_d > 1)/P(Z_i > 1)$, $P(Z_d > 1)/P(Z_i < -1)$, $P(Z_d < 1)/P(Z_i > 1)$ and $P(Z_d < -1)/P(Z_i < -1)$.

4. Results

Descriptive analysis of the sample

The questionnaire is administered from March to August 2018, 383 valid samples are collected, 85 from female and 298 from male respondents. In total, 70 participants claimed to have 2–4 years of experience in their current job positions, 287 had 5–9 years of experience and 26 had 10 years or more. Table IV lists the surveyed industries and job positions. It is important to notice that most of the sample comprised production/manufacturing engineers working in the automotive industry.

Descriptive analysis of the items

Table V summarizes the results from the descriptive analysis of the items in AMT technologies as well as benefits gained. The median values and interquartile range (IQR) values are estimated for each group of respondents according to their job position, which are categorized; manager (37), supervisor (127) and engineer (219) for a faster comparison about their assessments. Also, Table VI illustrates the average of the medians for each latent variable and job position, where the values indicate that the three categories of respondents have similar appreciation regarding the AMT implementation level and the benefits gained.

Latent variable validation

Table VII summarizes the latent variable validation process. As it can be observed, all the latent variables show acceptable values in each index. For additional information on this validation process, please consult the supplementary material.

Structural equation modeling

Table VIII lists the model fit and quality indexes used to test the model. It is observed that all indexes have acceptable values. According to the *p*-values associated with APC, ARS and AARS, the model has enough predictive validity, whereas the values of VIF and AFVIF – both lower than 3.3 – demonstrate that the model is has no collinearity problems. Finally, according to the GoF, the model fits the data. The validated model is displayed in Figure 2.

Industry	Manager	Supervisor	Engineer	Total
Automotive	5	68	108	181
Machines	26	28	65	119
Electronics	2	15	24	41
Electrical	2	9	18	29
Logistics	2	4	2	8
Aerospace	0	3	2	5
Total	37	127	219	383

Table IV. Sample characterization

Variable	Items	Manager M	Manager IQR	Supervisor M	Supervisor IQR	Engineer M	Engineer IQR
Stand-alone systems	Computer-aided design (CAD)	4.17	1.95	4.11	1.64	4.07	1.65
	Computer-aided process planning (CAPP)	4.13	2.08	3.73	1.85	3.83	1.76
	NC/CNC or DNC machines	4.04	1.87	3.70	2.13	3.88	2.01
	Machines working with laser (MWL)	3.45	3.22	3.33	2.34	3.38	2.45
	Lifting robots	3.38	2.88	3.52	2.63	3.70	2.50
	Other robots	3.54	2.85	3.41	2.84	3.58	2.84
Intermediate systems	Automated storage and retrieval systems (AS/RS)	3.00	2.42	3.34	2.17	3.51	2.22
	Automated material handling systems (AMHS)	2.87	2.36	3.26	2.14	3.51	2.05
	Automated inspection and test equipment (AITE)	3.55	2.03	3.54	1.97	4.00	1.64
Integrated systems	Flexible manufacturing (cells or systems) (FMC/FMS)	3.94	1.78	3.48	1.98	3.90	1.74
	Computer-integrated manufacturing (CIM)	3.50	2.18	3.26	1.92	3.62	1.88
	Just in time (JIT)	3.78	2.00	3.71	1.96	3.89	1.61
	Material requirements planning (MRP)	4.08	1.58	3.99	1.63	4.06	1.51
	Manufacturing resource planning (MRP II)	4.02	1.67	3.94	1.80	4.03	1.52
Design benefits	Design time reduction from product design	3.56	2.11	3.91	1.63	3.84	1.54
	Reduced lead-time	3.65	1.98	3.90	1.51	3.76	1.49
	Quality in design	3.87	1.58	3.93	1.62	4.05	1.43
Process benefits	Less machinery	3.26	2.12	3.44	1.85	3.61	1.69
	Reduced product lot size	3.48	1.72	3.59	1.75	3.69	1.65
	Machine flexibility	3.52	1.82	3.73	1.80	3.88	1.63
	Process flexibility	3.83	1.56	3.72	1.58	3.93	1.53
	Volume flexibility	3.70	1.73	3.73	1.73	3.88	1.58
	Expansion flexibility	3.87	1.58	3.78	1.48	3.93	1.61
	Reduced waste and rework	3.59	1.84	3.72	1.64	3.96	1.74
Commercial benefits	Helps to keep up with competitors	4.00	1.40	3.95	1.52	4.00	1.52
	Prompt response to customer needs	3.65	1.56	3.74	1.58	3.93	1.55
	Early market entry	3.58	1.72	3.78	1.52	3.88	1.55
	Shorter delivery times	3.64	1.66	3.93	1.70	4.01	1.50
	Increased sales	3.72	1.61	3.90	1.57	4.13	1.48

Table V. Descriptive analysis of items

Latent variable	Manager (37)	Supervisor (127)	Engineer (219)
Stand-alone systems	3.79	3.63	3.74
Intermediate systems	3.14	3.38	3.67
Integrated systems	3.84	3.67	3.90
Design benefits	3.69	3.91	3.88
Process benefits	3.61	3.67	3.84
Commercial benefits	3.72	3.86	3.99
Great average	3.63	3.69	3.84

Table VI. Average of medians

Direct effects

The model detailed in Figure 2 illustrates the nine research hypotheses, along with their corresponding β, p and SE values. Since all the p-values are lower than 0.5, it is concluded that the nine research hypotheses are all statistically significant at a 95% confidence level. Regarding the β values, they are estimated coefficients of the independent variables that indicate a change on the dependent variables caused by a unit change. Finally, SE values represent the percentage of variance in each dependent variable that is caused by an independent variable. For instance, the results for *H1* can be interpreted as follows: there is enough statistical evidence to claim that stand-alone systems implemented in production

Table VII.
Latent variable validation

Indexes	Stand-alone systems	Intermediate systems	Integrated systems	Design benefits	Process benefits	Commercial benefits
R^2 (⩾0.2)				0.476	0.347	0.414
Adj. R^2 (⩾0.2)				0.472	0.341	0.409
Composite reliability (⩾0.7)	0.871	0.867	0.880	0.929	0.933	0.922
Cronbach's α (⩾0.7)	0.705	0.693	0.796	0.898	0.915	0.894
Average variance extracted (AVE) (⩾0.5)	0.772	0.765	0.710	0.766	0.664	0.703
Full Collin. VIF (⩽5)	1.847	2.611	2.669	2.874	2.144	2.856
Q^2 (⩾0)				0.478	0.349	0.415

Table VIII.
Model fit and quality indices

Index and criteria	Value	p-value
Average path coefficient (APC, $p < 0.05$)	0.243	< 0.001
Average R^2 (ARS, $p < 0.05$)	0.412	< 0.001
Average adjusted R^2 (AARS, $p < 0.05$)	0.407	< 0.001
Average block VIF (AVIF, acceptable if ⩽5)	2.143	
Average full collinearity VIF (AFVIF, acceptable if ⩽5)	2.509	
Tenenhaus GoF (GoF, ⩾0.36)	0.584	

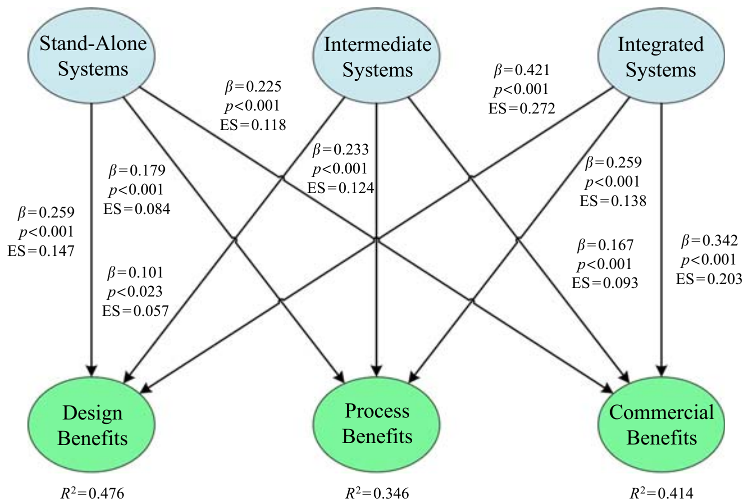

Figure 2.
Evaluated model

processes have a positive direct effect on design benefits, since when the first latent variable increases in 1 standard deviation, the second latent variable increases in 0.259 standard deviations. Likewise, in this relationship, SE = 0.147 indicates that stand-alone systems can explain 14.7 percent of the design benefits variable.

The previous information indicates that technologies, such as CAD, CAPP and NC/CNC/DNC machines, contribute to obtain design benefits, such as: reduction in design and conceptualization time for a product, because the correlation value is 0.468, while for the CAPP is 0.436. Similarly, CAD has a correlation of 0.435 with a design time reduction; however, it does not mean that CN/CNC/DNC do not contribute to obtain design benefits, those are only the highest relationships (see correlation among items in the supplementary material).

The remaining hypotheses can be interpreted in the same sense; all these interpretations are summarized in Table IX. For further information about this section, including *t*-values and confidence intervals, please consult the supplementary material.

Sensitivity analysis

Table X summarizes the results for the sensitivity analysis to estimate the probability of occurrence for a series of AMT implementation scenarios and benefits. According to the conjoint probability analysis, it is found that the probability for a maquiladora company to obtain high levels of both design benefits (+) and stand-alone systems (+) at the same time is low, being *&* = 0.086. Regarding the conditional probability analysis, it is found that high levels in design benefits (+) are very likely to occur when the level of implementation of stand-alone systems is high, being *if* = 0.446. These results confirm that technologies, such as CAD/CAPP and CNC machines, provide important design benefits.

It is also found that low implementation levels of stand-alone systems are not associated with high levels in design benefits, since *&* = 0.008 and *if* = *0.054*. However, low implementation levels of stand-alone systems can be related to low levels in design benefits, being *if* = 0.321, and unfortunately, these results imply a risk for managers. Fortunately,

Hypotheses	Independent variable	Dependent variable	*B*-value	*p*-value	ES	Conclusion
H1	Stand-alone systems	Design benefits	0.259	< 0.001	0.147	Accepted
H2	Intermediate systems	Design benefits	0.101	= 0.023	0.057	Accepted
H3	Integrated systems	Design benefits	0.421	< 0.001	0.272	Accepted
H4	Stand-alone systems	Process benefits	0.179	< 0.001	0.084	Accepted
H5	Intermediate systems	Process benefits	0.233	< 0.001	0.124	Accepted
H6	Integrated systems	Process benefits	0.259	< 0.001	0.138	Accepted
H7	Stand-alone systems	Commercial benefits	0.225	< 0.001	0.118	Accepted
H8	Intermediate systems	Commercial benefits	0.167	< 0.001	0.093	Accepted
H9	Integrated systems	Commercial benefits	0.342	< 0.001	0.203	Accepted

Table IX.
Conclusions on research hypotheses

			Independent latent variables					
			Stand-alone systems		Intermediate systems		Integrated systems	
		Level	+	−	+	−	+	−
Dependent latent variables		*P*(*Z*)	0.193	0.146	0.151	0.149	0.149	0.172
Design benefits	+	0.185	*&* = 0.086	*&* = 0.008	*&* = 0.070	*&* = 0.008	*&* = 0.089	*&* = 0.005
			If = 0.446	*If* = 0.054	*If* = 0.466	*If* = 0.053	*If* = 0.596	*If* = 0.030
	−	0.120	*&* = 0.005	*&* = 0.047	*&* = 0.008	*&* = 0.063	*&* = 0.003	*&* = 0.073
			If = 0.027	*If* = 0.321	*If* = 0.052	*If* = 0.421	*If* = 0.018	*If* = 0.424
Process benefits	+	0.164	*&* = 0.063	*&* = 0.003	*&* = 0.065	*&* = 0.005	*&* = 0.070	*&* = 0.005
			If = 0.324	*If* = 0.018	*If* = 0.431	*If* = 0.035	*If* = 0.474	*If* = 0.030
	−	0.178	*&* = 0.016	*&* = 0.055	*&* = 0.010	*&* = 0.068	*&* = 0.008	*&* = 0.078
			If = 0.081	*If* = 0.375	*If* = 0.069	*If* = 0.456	*If* = 0.053	*If* = 0.455
Commercial benefits	+	0.167	*&* = 0.073	*&* = 0.008	*&* = 0.065	*&* = 0.010	*&* = 0.063	*&* = 0.008
			If = 0.378	*If* = 0.054	If = 0.431	*If* = 0.070	*If* = 0.421	*If* = 0.045
	−	0.180	*&* = 0.005	*&* = 0.055	*&* = 0.005	*&* = 0.063	*&* = 0.003	*&* = 0.091
			If = 0.027	*If* = 0.375	*If* = 0.034	*If* = 0.421	*If* = 0.018	*If* = 0.530

Table X.
Sensitivity analysis

high implementation levels of stand-alone systems cannot be associated with low levels in design benefits, being *&* = 0.005 and *if* = 0.027, where these results imply that investing in stand-alone systems contributes to acquire the expected benefits. All the scenarios summarized in Table X can be interpreted similarly.

Table X helps estimate probabilities of occurrence between an independent latent variable and a dependent latent variable. However, to determine how all the best AMT implementation scenarios may have an impact on all the studied AMT benefits, the following formulas are applied:

- *P* (Design benefits+/(Stand-alone systems + *&* Intermediate systems + *&* Integrated systems+)) = 0.720.
- *P* (Process benefits+/(Stand-alone systems + *&* Intermediate systems + *&* Integrated systems+)) = 0.560.
- *P* (Commercial benefits/(Stand-alone systems + *&* Intermediate systems + *&* Integrated systems+)) = 0.560.
- As can be observed, the proper implementation of all the AMTs guarantees all the benefits studied in this work: design, process and commercial benefits.

5. Discussion

Descriptive analysis

Table V shows the medians of the valuations from the three groups that answered the survey (managers, engineers and supervisors). Based on the technological level in the stand-alone systems category, it is observed that managers have a higher valuation for CAD, CAPP, NC/CNC and DNC machines, while the engineers who are in the production lines value more the robots; CAD being the most valued technology. Regarding the intermediate systems category, it is observed that the engineers have the highest rate for the AS/RS, AMHS and AITE, since they are fully operational systems in the production lines, where the engineer García-Alcaráz *et al.* (2019), with AITE systems is being the most valued in this category. Finally, for the integrated systems, it is observed that managers have higher valuations on the FMC/FMS, MRP and MRP II, while engineers have higher medians in CIM and JIT, with MRP being the most valued system; however, engineers also value MRP and MRP II well, which is due to the fact that this type of technology is strategic, as mentioned by Cheng *et al.* (2018), and since they require a high level of investment, performance is widely monitored by the senior management, as it is indicated by Cardoso *et al.* (2012).

Regarding the design benefits, it is observed that supervisors and engineers have the highest valuation, which is logical, since they are responsible for redesigning the products as well as their manufacture in the production system, therefore, they will know more than just the technological capabilities installed, as indicated by Realyvásquez-Vargas *et al.* (2014). According to the process benefits and commercial benefits, it is observed that engineers have the highest valuations, which makes sense for the first type of benefits, but it was expected that managers would be the ones who valued commercial benefits the most, since they are the ones that have a strategic focus. The previous information can be a result of a slow implementation of AMT in the maquiladoras, since it is the engineers and not the managers, who value the benefits obtained most, and often they do not have enough decision power in AMT investments according to García and Alvarado (2013).

On the other hand, intermediate systems and integrated systems are the technologies that most favor process benefits with a SE of 0.124 and 0.138, respectively, which makes sense, since they are directly connected to the production and storage systems of raw materials as well as finished products, therefore, these results agree with Ghomri and Sari (2017) who argue that the automatic storage systems give flexibility to the process, machines and to the volume of production. Finally, the integrated systems and stand-alone systems are the ones that better explain commercial benefits with a SE of 0.203 and 0.118, respectively, which is due to the fact that they allow a quick response to customers' demands, to an early entrance to the market and to decrease the delivery time, which agrees with García-Alcaraz *et al.* (2016) and Kenneth W. Green *et al.* (2019) based on studies associated with JIT.

Relationships among variables

According to the validated model (see Figure 2), the following conclusions can be proposed regarding the effects of AMTs on design benefits, process benefits and commercial benefits:

- Integrated systems contribute the most to design benefits, since they explain 27.2 percent of the variance of this dependent latent variable. Stand-alone systems have a much lower impact, being 14.7 percent the SE, whereas intermediate systems, in turn, contribute 5.7 percent. These results imply that systems, such as flexible manufacturing, CIM, JIT, MRP and MRP II ensure design benefits if they are properly implemented as well as integrated with stand-alone systems, such as CAD, CAPP and CNC machines. In fact, findings are consistent with those proposed by Adeyeri *et al.* (2019) and Baena *et al.* (2017), who claim that integrated systems are the best choice for moving toward both e-manufacturing and Industry 4.0, while Lupinetti *et al.* (2019) declare that new products are always requiring new designs that CAD helps to solve.
- Integrated systems explain most of the variance of process benefits, being SE = 13.8 percent. On the other hand, intermediate systems and stand-alone systems can explain 12.4 and 8.4 percent, respectively. These results demonstrate that, in order to obtain process benefits, systems such as FMC, CIM, JIT, MRP and MRP II must be implemented in a way that they support AS/RS, AMHS and AITE systems; however, intermediate systems can offer also those process benefits, because the difference between 13.8 and 12.4 percent is very close, which is due to the flexibility for managers. In other words, manufacturing companies must consider that integrated systems offer operating solutions in the production line, and that all the systems must evolve to a fully integrated manufacturing system. In this sense, authors, such as Lee (2003), began to address the fundamental tools for e-manufacturing, while Cheng and Bateman (2008) discuss the main characteristics and potential worldwide applications of this integrated manufacturing concept. Currently, that manufacturing integration concept can be summarized in the fully integrated Industry 4.0, as Muhuri *et al.* (2019) indicate.
- The direct effects of AMTs on commercial benefits explain 41.4 percent of the variability of this latent variable. However, integrated systems explain most of this percentage, being SE = 20.3 percent. In turn, stand-alone systems and intermediate systems explain 11.8 and 9.3 percent, respectively. These findings support the previous claim on the importance of implementing systems, such as FMC, CIM, JIT, MRP and MRP II to obtain essential benefits, not only in product design and production process, but also in commercial aspects, as it is indicated by García-Alcaraz *et al.* (2016) and Kenneth W. Green *et al.* (2019) in reports related to JIT. Moreover, those type of technologies increase sales, offer a prompt response to customers, decreases delivery times, and this claim is consistent with what Wang *et al.* (2017) found when analyzing both JIT and MRP, or with what Miclo *et al.* (2016) stated that after analyzing the integration of MRP with both customers' needs and demands.

However, the cost for integrated systems is elevated and perhaps a company that is not focused in new product development may prefer to pay special attention to intermediate systems and stand-alone systems, because they can offer together a similar performance with a low cost as mentioned by Delaram and Fatahi Valilai (2018).

Sensitivity analysis

Table X illustrates the sensitivity analysis where several information can be discussed. First, the probability of obtaining design benefits is 0.446 if stand-alone systems are implemented, 0.466 if intermediate systems are successfully applied and 0.596 if integrated systems are correctly implemented. In conclusion, integrated systems are the cornerstone of the maquiladora industry, as they largely contribute to design benefits. Nevertheless, if the three types of AMTs are all properly implemented in a production process, the probability of obtaining design benefits is much higher and equal to 0.720.

The probability of obtaining process benefits is 0.324 if stand-alone systems are properly implemented, 0.324 if intermediate systems are correctly applied and 0.474 if integrated systems are successfully implemented. However, when all the AMTs are properly implemented in a production process, the probability of obtaining process benefits is 0.560. These results indicate that manufacturing companies must focus their efforts to increase the level of integration of the AMTs implemented in their systems, because it guarantees new production flexibility and capacity as it is indicated by García-Alcaráz *et al.* (2019).

Finally, the probability of obtaining attractive commercial benefits is 0.378 if stand-alone systems are properly implemented, 0.431 if intermediate systems are correctly applied and 0.421 if intermediate systems are successfully performed. On the other hand, when all the AMTs are properly implemented in a production process, the probability of obtaining commercial benefits is 0.560. This finding confirms the suggestion from Burcher and Lee (2000) and Koc and Bozdag (2009) that point out that AMT are source of competitiveness.

6. Conclusions, limitations and future research

Stand-alone systems, such CAD, CAPP, NC machines, MLWL, and robots integrated to the manufacturing industry known as the maquiladora sector, always guarantee design benefits, such as low time in design and redesign process as well as quality in design, consequently, a low lead-time from design to manufacturing process. Specifically, CAD and CAPP are the most significant for obtaining a flexible manufacturing production system that will enable to have reduced lot sizes and volume flexibility. This category is not expensive and the human skills required are small, since most maquiladoras have access to this type of technology.

Intermediate systems, such as FMC, CIM, JIT, MRP, and MRP II enable manufacturing companies to obtain attractive benefits in production processes and commercial aspects. For example, AS/RS, AMHS and AITE support the storage of heavy and fragile raw materials, reduce operators' accidents, materials loss, and help to detect low quality in the production process. This type of technology is more expensive than the stand-alone systems and requires more skills from human resources, and, almost all the maquiladora companies have access to this type of technology.

Finally, integrated systems like FMC/FMS, CIM, JIT, MRP and MRP II have the higher impact on design benefits, process benefits and commercial benefits. For example, CIM integrates a lot of modules that support the design, production process and material handling, whereas FMC/FMS support the flexibility required in the line production for uncertain demands, and technologies, such as JIT, MRP and MRP II support the material flow along the supply chain.

However, there are several different type of benefits obtained from the AMT implementation in a maquiladora; nevertheless, this paper has reported an SEM that integrates only three of them, which refers to design, production process and commercial applied to manufacturing companies, but it can be a limitation, since there were excluded aspects associated with human resources abilities to operate those technologies, economic income for the companies due to increased sales and prompt market entry, environmental concerns due to pollution, public policies from the host country, labor culture and other geographical characteristics. Therefore, studies in other geographical and industrial sector can report different findings; however, this report can be used as a general framework for future research studies.

As a matter of fact, future research will integrate those economic (Koc and Bozdag, 2009), environmental and organizational (Cardoso *et al.*, 2012) benefits that may affect human resources (Spanos and Voudouris, 2009) in a more holistic and realistic model, looking forward to have a better understanding about the impact that AMT have on production systems.

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