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The impact of information and communication technologies (ICT) on agility, operating, and economical performance of supply chain

García-Alcaraz, J.L.[a,*], Maldonado-Macías, A.A.[a], Alor-Hernández, G.[b], Sánchez-Ramírez, C.[b]

[a]Department of Industrial and Manufacturing Engineering, Universidad Autónoma de Ciudad Juárez, Mexico
[b]Division of Research and Graduate Studies, Instituto Tecnológico de Orizaba, Veracruz, Mexico

A B S T R A C T

Information and communication technologies (ICT) are widely used in supply chain (SC) due to their effects on both economic performance and operational agility. This paper proposes a structural equation model integrating 17 items into four latent variables: ICT, SC agility, operating performance, and economic performance. Data analysed in the model were gathered through a questionnaire administered to 306 managers of Mexican maquiladoras. Likewise, we used statistical software WarpPLS 5.0®, which is based on partial least squares algorithms, to assess the six hypotheses established in the model. Such hypotheses were validated with a 95 % confidence level, and values were standardized to avoid problems regarding the measurement scale. Findings demonstrate that ICT have a positive direct impact on the other three analysed latent variables, which together account for 63 % of the variability of SC economic performance. Similarly, we found that ICT can explain up to 40 % of the variability of SC agility.

A R T I C L E   I N F O

Keywords:
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**Corresponding author:*
jorge.garcia@uacj.mx
(García-Alcaraz, J.L.)

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1. Introduction

1.1 General

The recently emerged concept of globalization usually refers to a process in which a product is manufactured in one part of the world but includes components sub-assembled in other countries, while it can be consumed in another remote area. Consequently, globalized companies require large logistics systems to transport all these materials and components. Moreover, the process involves multiple actors sharing information, materials, and above all, financial resources [1]. This set of activities is commonly called supply chain (SC).

To improve SC metrics, companies currently rely on a wide range of information and communication tools, which are traditionally categorized into two groups: communication technologies and information technologies [2]. It is common, however, to include both concepts in one, and thus refer to them as information and communication technologies (ICT).

Mexico currently caters for 5,074 foreign-owned assembling plants, also known as maquiladoras, whose parent companies are headquartered overseas and provide them with specialized *ICT* to comply with production orders. The maquiladora program became attractive after Mexico, the US, and Canada signed the North American Free Trade Agreement (NAFTA). The treaty created an appealing and convenient free trade zone for these countries, which enabled

US and Canadian companies to import raw materials in Mexico and export finished products at preferential tariffs. As a result, maquiladoras became a key industry in Mexico, especially along the Mexico-US border.

In Ciudad Juárez, a border city located in the state of Chihuahua, the maquiladora industry is represented by 326 manufacturing companies, directly offering 222,040 jobs. These maquiladoras belong to a globalized SC, whose performance can be compromised by many factors, such as ICT. Therefore, to contribute to the discussion on the impact of ICT on supply chain performance, this paper seeks to measure the effects of *ICT* on SC *Agility*, *Operating Performance* and *Economic Performance*, thereby looking to support decision-making in Mexican maquiladoras on ICT implementation. More specifically, results here provided may help executives identify the most important activities to gain certain benefits. Note that similar studies have been conducted in other industrial sectors by Garcia-Alcaraz et al. [3] and Martinez-Loya et al. [4].

1.2 Information and communication technologies in supply chain

In the industrial sector, *ICT* are mainly used to monitor and control the flow of materials in supply chains. From this perspective, benefits gained from *ICT* implementation are vast and varied; the most illustrative examples include:

- *SC visibility*: *ICT* enable to monitor the material flow along the SC at any time, and sometimes with remote access [5]. Visibility has been studied from several SC perspectives, such as inventory control [6], risks visibility from cash break down, information, or materials flow [7], and visibility as a result of interaction and collaboration among SC partners [8, 9], among others.
- *SC agility*: Research has reported agility as one of the major *ICT* benefits [10]. However, because SC agility is one of the four variables studied in this paper, we will not provide further details on this element in this section.
- *SC flexibility*: It refers to the way companies make necessary changes to meet customer demands. Flexibility must be designed and planned [11] from the supplier evaluation phase [12], although lack of flexibility can be improved with appropriate plant localization [13] and proper use of *ICT* [14]. In fact, *ICT* generate predictive models that stimulate flexibility and facilitate decision-making based on metrics and their analysis [15].

1.3 Supply chain agility

SC agility usually refers to how fast production processes and material flows are [16], although it is frequently confused with flexibility. Since SC agility has been studied from many different points of view, many models have been proposed to measure it [17]. Agility is thus a strategy deserving serious management, since undoubtedly, companies with agile SCs have greater competitive potential [2]; however, in order to achieve agile SCs, firms require solid integration among SC members, which is often reached with *ICT* implementation [18].

Nevertheless, agility is not merely an *ICT* product or the result of SC members' integration. Agility also and mainly derives from the effort and dedication of people involved in the SC [10], and it offers attractive advantages to customers. Such benefits later translate into economic benefits, which obviously reflect on increased financial profits [19]. From this perspective, recent studies have reported that *Agility* in wineries is gained through *ICT* implementation [3], and under such argument, we propose the first working hypothesis of this study, H_1: In the maquiladora industry, *ICT* implementation along the SC has a positive direct effect on *Agility*.

1.4 Operating performance

In order to improve a process, it is necessary to know its current state and then make a comparative analysis. In other words, *Operating Performance* must be monitored to be improved. Nowadays, several indices and indicators serve this purpose, and when *Operating Performance* is improved (maximize or minimize), sooner or later results are converted into profits. Currently, companies rely on a wide range of internal *ICT* to assess and enhance *Operating Performance*. Some of these *ICT* include Enterprise Resource Planning (ERP) [20], Warehouse Management

System (WMS), bar codes, and Radio Frequency Identification (RFID) [21]. One benefit of using these kinds of *ICT* is SC risks reduction [22].

One of the most important performance indices is cycle times. Short time cycles imply that products spend a little time in inventory and are rapidly manufactured and delivered to customers [23]. However, cycle times are affected by inventory policies and the company's ability to make appropriate demand forecasts [24]. Also, cycle times can be reduced through SC members integration and information sharing [25]. In this sense, the use of mobile technologies has become a trend [26].

Although cycle time reduction must be priority, ensuring unrejected deliveries is equally important, as they imply customer satisfaction [27]. This means that managers must focus on guaranteeing short and fast cycle times without lowering product quality. In this sense, cycle times must be supervised using *ICT* along the SC to guarantee visibility [4], whereas customer complaints do require another SC *Operating Performance* metric. To find a relationship between *ICT* and SC *Operating Performance* in the maquiladora context, we propose the second working hypothesis, H_2: In the maquiladora industry, *ICT* implementation has a positive direct effect on SC *Operating Performance*.

Operating Performance indices can have several improvement sources, such as proper *ICT* integration; however, they can also be enhanced through *Agility* [28] and proper SC alignment with the corporate vision and mission [29]. For instance, by using factor and cluster analyses, authors in Kisperska-Moron and Swierczek [30] grouped a set of polish companies according to SC agility, whereas an empirical study conducted by Ngai et al. [31] reported the effects of SC *Agility* on productivity indices. Therefore, to analyse the impact of SC *Agility* on SC *Operating Performance*, we propose the third working hypothesis as follows, H_3: In the maquiladora industry, SC *Agility* has a positive direct effect on SC *Operating Performance*.

1.5 Economic performance in supply chain

Companies implement production, quality, and management methodologies, techniques, procedures, and technologies in SC to increase profits, which is why research on SC benefits has different origins and purposes. From this perspective, some of the studies associating *ICT* with SC performance have focused on the use of ERP, one of the most popular methods for materials handling. Also, Kanellou and Spathis [32] evaluated SC performance in terms of financial impact, whereas research in [33] analysed the same phenomenon in Chinese companies. Furthermore, the study in Teittinen et al. [34] reported that *ICT* implementation in SC was vital for companies in emerging countries. Hence, in order to contribute to the discussion on the economic benefits of ICT implementation for SCs, we propose the fourth working hypothesis as follows, H_4: In the maquiladora industry, *ICT* implementation has a positive direct effect on *Economic Performance*.

Another source of profits is SC *Agility*, since it guarantees customer satisfaction through rapid deliveries [19] and allows companies to quickly and efficiently adapt to the needs of these clients. Unfortunately, as mentioned in Silvestre [35], senior managers generally but incorrectly associate agility with high production costs. However, a study conducted by Yang [36] using path analysis showed that by using *ICT*, Chinese manufacturing companies could increase *Agility* and achieve greater *Economic Performance*, whereas authors in Yusuf et al. [37] reported similar results in the petroleum industry in the United Kingdom. Therefore, in the context of Mexican maquiladoras, we can propose the following working hypothesis to assess the effects of SC *Agility* on *Economic Performance*, H_5: In the maquiladora industry, SC *Agility* has a positive direct effect on *Economic Performance*.

SC *Operating Performance* can quickly turn into economic benefits. From this perspective, product quality, low costs, and fast deliveries are top priorities, because they are synonyms of satisfied customers [38] and a rapid and continuous material flow, and thus they demonstrate effective SC integration [39]. Similarly, short cycle times are always beneficial from an economic point of view [40], whereas quick setups may allow for product customization, which is often profitable. Considering thus the impact of SC *Operating Performance* on the *Economic Performance* of companies, we propose the sixth working hypothesis for the maquiladora industry, H_6:

In the maquiladora industry, SC *Operating Performance* has a positive direct effect on *Economic Performance*.

Fig. 1 depicts the proposed model to test the six hypotheses discussed above.

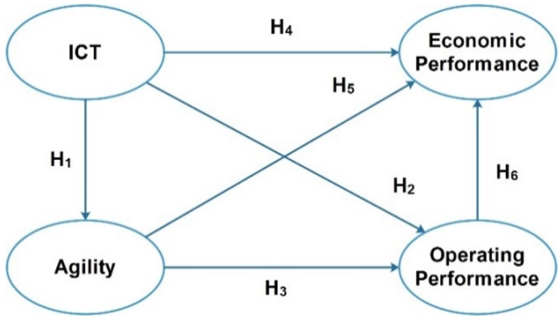

Fig. 1 Proposed model

2. Methodology

2.1 Questionnaire design

As data collection instrument, we designed a questionnaire to assess the four latent variables and their corresponding items. Latent variable *ICT* included seven items, while SC Agility was composed of three items; *Operating Performance* was formed of five items, and *Operating Performance* was assessed by two items. Table 1 lists the assessed items for each latent variable and references justifying their study.

The questionnaire had to be answered using a five-point Likert scale for subjective assessments, where the lowest value (1) indicated that an activity had never been performed or a benefit had never been obtained. On the other hand, the highest value (5) implied that an activity had always been performed or a benefit had always been gained.

Table 1 Analysed Latent Variables and Items

ICT	*Operating Pperformance*
Effective use of the Internet in B2B commerce [41].	In-full and on-time deliveries [5].
Effective use of the Internet for business management [42].	Customer satisfaction (no claims or warnings) [39, 43].
Use of the Internet for product customization and collaboration [42].	Short supplier-customer time cycle [44].
Displayed information and inter-organizational coordination [41, 45].	SC visibility [5, 46].
Use of Intra-Organizational Information Systems for SC coordination and integration [42, 47].	High-levelled product customization [39, 43].
SC optimization through ECR [48].	*Agility*
Removal of SC intermediaries [49].	Fast re-engineering process [50, 51].
Economic performance	Ability to respond to unexpected customer demands [45, 51].
SC costs reduction [39].	Ability to respond to high market fluctuations [35].
SC performance contributes to cash flow [29, 52].	

2.2 Data collection process

To collect information, we stratified the sample by focusing on 306 companies established in Ciudad Juárez (Mexico), which have mature SCs. Then, we invited potential participating companies to schedule a survey administration meeting, depending on their availability. For companies that did not respond to the first invitation, a second request was emailed two weeks later; however, after three unsuccessful attempts, the case was discarded. As regards the survey administration process, we conducted face-to-face interviews with SC managers and personnel directly involved in the materials flow process.

2.3 Data capture and questionnaire validation

Collected data were analysed using statistical software SPSS 21®. However, before any data validation process, we conducted statistical tests to identify missing values and outliers. Missing values were replaced by the median value of items, as long as they did not exceed 10 % in each survey, while outliers were solved by standardizing values [54]. Similar procedures have been followed in other SC studies [55].

As for data validation, we first computed the Cronbach's alpha and composite reliability indices for every latent variable to test internal validity and consistency, setting 0.7 as minimum acceptable value [53]. Then, since removing items from latent variables can improve their reliability, we ran additional tests, relying on five indices: Average Variance Extracted (AVE), Variance Inflation Factors (VIF), Q-Squared, R-Squared, and Adjusted R-Squared. This procedure has been used in previous SC research to validate other data collection instruments [29, 52].

AVE was used to measure discriminant validity of latent variables, setting 0.5 as the minimum acceptable value [56], while we relied on VIF as collinearity measure, whose maximum value was set to 3.3 [57]. Finally, since we dealt with ordinal data, we computed Q-squared index as measure of nonparametric predictive validity, and R-squared and Adjusted R-Squared as measures of parametric predictive validity. We expected to obtain similar values in both R-squared and Adjusted R-Squared indices.

2.4 Descriptive analysis of items

Following the data validation process, we conducted a descriptive analysis of items to find measures of central tendency and data dispersion. We estimated the median or 50-th percentile as measure of central tendency and the interquartile range (IQR) as measure of data dispersion. On one hand, high median values suggested that an activity was always performed or a benefit was always gained in the Mexican maquiladora industry, whereas low values indicated that an activity was never performed or a benefit was never gained. On the other hand, high IQR values indicated low consensus among respondents as regards the median value of an item, whilst low values suggested high consensus [58].

2.5 Structural equation modelling

To test hypotheses depicted in Fig. 1 and discussed in the introduction section, we employed Structural Equation Modelling (SEM). SEM is a multivariate analysis technique widely used in SC research to statistically validate causal relationships between latent variables. For instance, a SEM-based study conducted by [59] reported the impact of JIT on SC performance, whereas authors in [60] assessed the effects of uncertainty on SC financial performance by means of a structural equation model. Likewise, SEM-based research by [61] reported the effects of green SC management on competitiveness and market incentives.

In this research, the structural equation model was run on WarpPLS 5.0® software. More specifically, we employed WarpPls3 PLS algorithm, since partial least squares (PLS) algorithms are widely recommended for small-sized samples or when using non-ordinal data [62]. Then, to validate the model, we computed three model fit and quality indices, proposed by [62] and used by [63] in SC environments: Average Path Coefficient (APC), Average R-Squared (ARS), and Average block Variance Inflation Factor (AVIF).

APC and ARS were used to measure the model's general efficiency and predictive validity, respectively. In both cases, we computed the P-values to determine statistical significance of parameters, setting 0.05 as the threshold, and thus testing null hypotheses APC = 0 and ARS = 0, versus alternative hypotheses: APC≠0 and ARS≠0. As for AVIF, we computed it as internal collinearity measure, accepting any value lower than 5.

Once indices were estimated, we measured and validated three types of effects between latent variables: direct, indirect, and total effects. Direct effects are depicted in Fig. 1 as arrows directly connecting two latent variables, whereas indirect effects occur through mediator variables, and total effects are the sum of direct and indirect effects for every relationship. For every effect, we estimated a P-value to determine its statistical significance, setting 0.05 as the threshold, thus implying that validated effects were significant at a 95 % confidence level. Finally, for each dependent latent variable we decomposed the value of R^2 into all the effect sizes caused by independent latent variables.

3. Results

3.1 Sample description

As previously mentioned, we validated 306 surveys administered in Mexican maquiladoras from Ciudad Juárez. As regards the sample characteristics, Table 2 compares participant's gender with length of work experience. As can be observed, 233 males and 73 female managers were surveyed. Also, most respondents had from one to two years of work experience in their current position, although 57 people had more than ten years of work experience.

Table 2 Gender and job experience (years)

Gender	Experience (years)				Total
	1-2	2-5	5 - 10	>10	
Male	90	64	25	54	233
Female	36	20	14	3	73
Total	126	84	39	57	306

Table 3 shows surveyed industries and their size, measured by number of employees. Note that only 278 of the 306 participants reported such information. In this sense, the table shows that 93 automobile and electronics manufacturers were surveyed, while 51 of the studied maquiladoras belonged to the aeronautics sector. However, the medical or surgical sector was the least prominent industry, with only 21 reported cases. As regards company size, all surveyed maquiladoras can be considered large, since they reported more than 500 employees in operation.

Table 3 Industrial sector and size of companies surveyed

Industrial sector	Number of employees					Total
	1-50	51-100	101-200	201-500	>501	
Automotive	3	3	6	9	72	93
Electronics/Electrical	7	8	8	17	53	93
Plastic	1	0	1	3	10	15
Packaging	1	0	1	1	2	5
Aeronautics	15	8	8	5	15	51
Medical	0	21	0	0	0	21
Total	27	41	24	35	152	278

3.2 Questionnaire validation

For data validation, we measured reliability of latent variables using seven indices as described in the methodology section. Results from this data validation process are shown in Table 4. Values obtained for R-squared and adjusted R-squared indices demonstrated that latent variables had enough predictive validity. Likewise, since values of the composite reliability index and the Cronbach's alpha were above 0.7, we concluded that all latent variables had sufficient internal consistency. Also, we found enough discriminant validly and no collinearity problems in data, since AVE values were above 0.5 and VIF values were below the threshold (3.3). Finally, since we obtained Q-squared values similar to their corresponding R-squared values, we demonstrated that all latent variables showed predictive validity from both parametric and non-parametric perspectives.

Table 4 Statistical validation of latent variables

Index	Latent variable			
	ICT	*Agility*	*Operating performance*	*Economic performance*
R-squared		0.397	0.627	0.459
Adjusted R-squared		0.395	0.624	0.455
Composite reliability	0.933	0.889	0.916	0.874
Cronbach's alpha	0.916	0.813	0.817	0.819
AVE	0.667	0.729	0.846	0.581
VIF	1.757	2.142	2.691	2.718
Q-squared		0.400	0.627	0.453

3.3 Descriptive analysis of items

Table 5 shows results from the descriptive analysis of items, which are sorted in descending order based on their median values. According to participants, item *Effective use of the Internet in B2B commerce* is the most important *ICT* activity (median value = 4.26). However, in terms of SC *Agility*, the most valuable feature is *Ability to respond to unexpected customer demands* (median value = 4.38). In the case of SC *Operational Performance*, managers from Mexican maquiladoras considered item *In-full and on-time deliveries* as the most important activity, with a median value of 4.39. Finally, as for *Economic Performance*, the sample reported *SC costs reduction* as the most important element (median value = 4.2).

Table 5 Descriptive analysis of items

ICT	**Median**	**IR**
Effective use of the Internet in B2B commerce.	4.26	1.39
Effective use of the Internet for business management.	4.26	1.32
Displayed information and inter-organizational coordination.	4.18	1.49
Intra-organizational Information Systems for SC coordination and collaboration.	4.18	1.37
Removal of SC intermediaries.	4.18	1.47
Use of the Internet for product customization and collaboration.	4.15	1.45
SC optimization through ECR.	4.10	1.45
Agility		
Ability to respond to unexpected customer demands.	4.38	1.26
Ability to respond to high market fluctuations.	4.31	1.38
Fast re-engineering process.	4.16	1.44
Operating performance		
In-full and on-time deliveries.	4.39	1.21
Customer satisfaction (no claims or warnings).	4.26	1.34
High-levelled product customization.	4.18	1.35
Short supplier-customer time cycle.	4.14	1.43
SC visibility.	4.12	1.37
Economic performance		
SC costs reduction.	4.2	1.39
SC performance contributes to cash flow.	4.12	1.35

3.4 Direct effects and hypotheses validation

Figure 2 shows the model evaluated as described in the methodology section. Every effect includes a beta (β) value and a P-value; the former is a measure of dependency, whereas the latter was used to determine statistical significance of effects at a 95 % confidence level. Note that all P-values are below 0.05, demonstrating that all beta parameters were statistically significant and had to remain in the model. The figure also shows the percentage of explained variance in every dependent latent variable (R^2). In this sense, we found that *Economic Performance* was 63 % explained by the three other latent variables, since $R^2 = 0.63$. Similarly, *Operating Performance* was 46 % explained by SC *Agility* and *ICT*, since in this case $R^2=0.46$.

As regards model fit and quality indices, we obtained the following results: Average Path Coefficient (APC) = 0.396 (with $P < 0.001$); Average R-Squared (ARS) = 0.572 (with $P < 0.001$); Average Adjusted R-Squared (AARS) = 0.571 (with $P < 0.001$); and Average block VIF (AVIF) = 2.234 (ideally <= 3.3). Since these indices demonstrated model's adequacy, we could formulate accurate conclusions on the sixth hypotheses proposed in the introduction section. Such conclusions are presented in Table 6, where based on β-values, the highest positive direct effect occurred from *ICT* on *Agility*, implying that when the former increased its standard deviation by one unit, the latter increased by 0.63 units (β = 0.63).

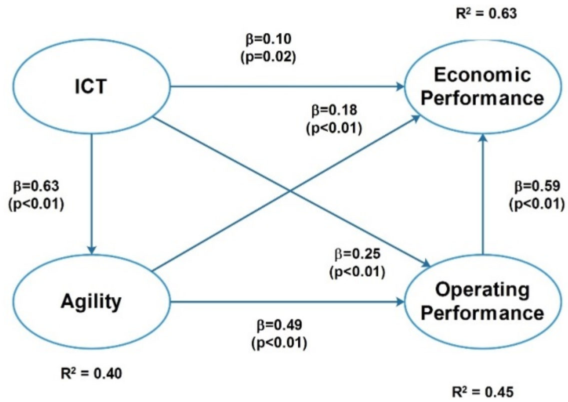

Fig. 2 Evaluated model

Table 6 Direct effects – tested hypotheses

Hypothesis	Independent variable	Dependent variable	β- and P-values	Conclusion
H_1	*ICT*	*Agility*	0.63 (P < 0.01)	Accepted
H_2	*ICT*	*Operating performance*	0.25 (P < 0.01)	Accepted
H_3	*Agility*	*Operating performance*	0.49 (P < 0.01)	Accepted
H_4	*ICT*	*Economic performance*	0.10 (P = 0.02)	Accepted
H_5	*Agility*	*Economic performance*	0.18 (P < 0.01)	Accepted
H_6	*Operating performance*	*Economic performance*	0.59 (P < 0.01)	Accepted

3.5 Total indirect effects

Indirect effects occur through mediator variables using two or more model segments; they are important, since they can explain relationships that initially seemed to be statistically non-significant. In this research, Table 7 shows the sum of indirect effects between latent variables, including statistical validation given by P-values, and the effect size, ES. ES is similar to R^2 of direct effects, and it expresses the percentage of explained variance in dependent latent variables. As can be observed, *ICT* have strong indirect effects on both *Economic Performance* and *Operating Performance,* with values β = 0.447 and β = 0.307, respectively.

Table 7 Indirect effects

To	From	
	ICT	*Agility*
Economic performance	0.447 (p < 0.001) ES = 0.247	0.29 (p < 0.001) ES = 0.172
Operating performance	0.307 (p < 0.001) ES = 0.172	

3.6 Total effects

Total effects are the sum of direct and indirect effects. Table 8 introduces total effects found in each relationship between latent variables, which based on the P-values, were all statistically significant. Also, it was found that *ICT* had high total effects on all the other latent variables, thereby demonstrating the importance of *ICT* implementation in SC. Also, note that the highest ICT effect occurred on SC *Agility* (β = 0.63 units), whereas *ICT* impact on *Operating Performance* seemed a little lower (β = 0.561). Also, we found that SC *Agility* had significant total effects on *Operating Performance* (β = 0.488) and *Economic Performance* (β = 0.47).

Table 8 Total Effects

To	From		
	ICT	*Agility*	*Operating performance*
Agility	0.63 (p < 0.001) ES = 0.397		
Economic performance	0.547 (p < 0.001) ES = 0.303	0.47 (p < 0.001) ES = 0.300	0.594 (p < 0.001) ES = 0.457
Operating performance	0.561 (p < 0.001) ES = 0.315	0.488 (p < 0.001) ES = 0.316	

4. Conclusions, industrial implications, and future work

In this research, we provided quantitative dependency measures to demonstrate that ICT implementation has effects on SC agility and operating and economic performance. These findings look trivial and with common sense, but those dependence values represent the main contribution given in this paper. Results introduced in Fig. 2 thus validated the six hypotheses as statistically significant, and they can thus support decision-making in Mexican maquiladoras on ICT implementation as a profitable strategy.

Findings here reported also support *ICT* implementation as a source of competitiveness, since they allow companies to increase SC *Agility* and visibility, which both impact on *Operating Performance* and *Economic Performance*. In this sense, we found that the *ICT* effects on *Economic Performance* only increased when SC *Agility* and *Operating Performance* were present, since the indirect effect in this relationship was higher than the direct effect (β = 10 vs. B = 0.447). Similar results were reported in the wine industry by Garcia-Alcaraz et al. [3] and Martínez-Loya et al. [4].

Similarly, this study argues that *ICT* allow for a faster response to customer needs by streamlining changes resulting from demand uncertainty. This argument is supported by the relationship found between *ICT* and *Agility*, which showed the highest direct effect (β = 0.63), and in which the former explained 40 % of the variance of the latter ($R^2 = 0.40$).

In this research we found that indirect effect from *ICT* on *Operating Performance* given through *Agility* was higher (β = 0.307) than the direct effect (β = 0.25), and total effects equalled 0.561 units. Similar findings were obtained in the relationship between *Agility* and *Economic Performance*, in which the direct effect was 11 units below the indirect effect (β = 0.18 vs. B = 0.29) given through *Operating Performance*. Such results entail the following industrial implications*:*

- Company executives and SC managers must encourage ICT implementation to meet SC and corporate demands. However, it is equally important to properly plan *ICT* implementation, and provide adequate training on the use of ICT, since their success impact on SC *Agility* and *Operating Performance.*
- SC visibility is key to the production processes, since it supports companies in making on-time decisions and rapid production process changes.
- Managers must pursuit all operating benefits provided by *ICT* and SC *Agility*, since both elements guarantee proper *Operating Performance*, and thus increase *Economic Performance*.

Finally, as future research, we will seek to provide full explanation for explained variance of latent variables, since R^2 obtained in this study did not reach the unit. To achieve this goal, we will analyse technological levels and updates of *ICT*, as well as the role of support and maintenance equipment in SC performance.

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