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Effects of Human Factors and Lean Techniques on Just in Time Benefits

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Received: 27 February 2019; Accepted: 13 March 2019; Published: 28 March 2019

Abstract: A successful Just in Time (JIT) implementation is based on human resources integration (managers, operators and suppliers) and other lean manufacturing techniques applied in the production process. However, the relationship between these variables is not easily quantified. This paper reports a structural equation model that integrates variables associated with JIT implementation: management commitment, human resources integration, suppliers and production tools and technique, which affect the benefits gained, and are integrated into nine hypotheses or relationships among then. The model is evaluated with information from 352 responses to a questionnaire applied to manufacturing industry, and partial least squares technique is used to evaluate it. The direct effects, sum of indirect effects, and total effects are quantified, and a sensitivity analysis based on conditional probabilities is reported to know scenarios associated with low and high levels in variables' execution and how they impact the benefits obtained. Findings indicate that managerial commitment is the most important variable in the JIT implementation process, since managers are the ones that determine the relationships with suppliers, integrate human resources, and approve the lean manufacturing techniques and tools that support the JIT.

Keywords: JIT implementation; suppliers in JIT; operational benefits; human factor in JIT; material flow; structural equation model

1. Introduction

Nowadays, industrial product markets are globalized, which implies that manufacturers are usually based in one region, whereas customers may be in another. However, this globalization phenomenon has expanded to entire production systems, and as a result, many components of the same final product are often manufactured abroad. This resource optimization strategy, which many production systems adopt nowadays, involves handling product subassemblies and materials along an assembly line in a factory [1], which is usually strategically located close to its target market [2]. Unfortunately, the raw materials and parts transportation process generates costs that add no value to the final product and compromises the economical and green sustainability of companies. Moreover, the highest rates of losses and accidents occur at this stage, as a result of transportation delays, material mishandling, and perished goods, to name but a few factors. In fact, logistics and transportation costs can represent up to 70% of a final product's costs. In this sense, effective supply chain management (SCM) is a source of economic savings for improved sustainable indexes.

The supply chain (SC) is the network of activities, facilities, and distribution channels that are necessary to create and sell a product. An SC involves looking for and extracting raw materials, transporting these materials to a factory, distributing the final product, and delivering it to the final customers [3]. The management process of all these activities is known as SCM, which relies on a wide range of production tools, techniques, and philosophies aimed at reducing costs and increasing sustainability. One of the popular techniques is Just in Time (JIT), which supports the processes of raw material supply, transformation, and distribution as a final product [4]. Overall, JIT supports the production process by seeking to eliminate unnecessary supply-related costs, reduce machine downtimes, and ensure a correct flow in the production process, increasing economical and green sustainability. As a result of these actions, both administrative and operational costs are significantly reduced [5], which has a positive impact on the costs of a final product; however, JIT is supported by other techniques, such as Kanban [6], just in sequence (JIS) [7], cell production, operations standardization, line balancing, among others [8].

JIT as a technique aims at eliminating waste in the production process. In this sense, multiple research works have reported the benefits gained after a successful JIT implementation. For instance, García-Alcaraz, et al. [9] identified 31 JIT benefits in the production process, including increased productivity, increased product quality, increased employee motivation, less waste and rework, better process efficiency, better teamwork, greater process flexibility, reduced fixed costs, reduced manpower costs, lower space requirements, reduced inventory, reduced overhead expenses, reduced movement distances, improved resource utilization, less paperwork, less material handling, better supplier–customer relationships, and shorter lead times, among other things.

JIT benefits are appealing to production managers, yet the question is usually how to implement a JIT system in such a way as to obtain all its benefits and improve SC integration and increase sustainability. In other words, it is important to identify the critical success factors (CSFs) that ensure a successful JIT implementation. Fortunately, several works have explored this trend. In their research, Garcia-Alcaraz, et al. [10] reported 14 CSFs for JIT, including production strategy, *Managerial Commitment* (*MAC*), employee commitment and management, relationships with *Suppliers* (*SUP*), employee education and training in JIT, plant layout, organizational aspects related to JIT, sales and distribution system, corporate plans and environmental policies, among others (observe that in the document the latent variables appear in italics).

JIT is viewed more as a production philosophy than as a production technique, since its cornerstones are *Human Resources Integration* (*HRI*), including *SUP*, managers, and operators [11]. Also, Priestman [12] relates JIT with statistical quality control, whereas to Balakrishnan, et al. [13], the philosophy can be associated with customer loyalty costs. On the other hand, Cua, et al. [14] claim that JIT is not an isolated technique because it works along with techniques such as total quality management (TQM) and total productive maintenance (TPM). Finally, Fullerton, et al. [15] declare that JIT has a direct association with economic benefits, whereas Maiga and Jacobs [16] explored JIT on overall corporate performance.

Recent works have explored the benefits of JIT from different perspectives. For instance, Inman, et al. [17] found an important relationship between JIT and both *Operational Benefits* (*OBE*) and corporate performance. Likewise, García, et al. [18] link the JIT philosophy to economic benefits, while Green Jr, et al. [19] found that SC efficiency indices and organizational performance are positively affected by JIT.

JIT as an industrial technique is of academic interest, specifically at the integration stage of globalized corporations, since it has the potential to reduce production costs associated with both logistics and transportation, and as consequence, improve sustainability indexes. However, most research works consider JIT as a whole and do not break it down into its CSFs. As a result, these works focus merely on the operational and technical aspects of JIT. Moreover, few works have quantified the relationship between the CSFs from JIT and their corresponding benefits, or have performed a sensitivity analysis on the different states of the variables. To address these gaps, our research seeks to explore the effects of human factors on JIT benefits under a quantitative perspective. Namely, we seek to find a measure of dependency between the analyzed CSFs and their corresponding JIT benefits. Moreover, we aim at reporting the likelihood of occurrence of the dependent variables with respect to changes in the independent variables.

This research assumes that JIT is a production philosophy, and human resources are responsible for implementing it in production systems. Consequently, our work focuses on identifying and measuring the effects of human factors in the performance of companies that implement JIT. Specifically, we propose a structural equations model that integrates five main variables: *MAC*, *SUP*, *HRI*, *TTP* and *OBE*. Additionally, we study as the mediating variable the presence of other manufacturing tools in the production process. We justify the presence of this mediating variable with the claim that JIT is not an isolated tool, as it works along with other tools, such as TPM, TQM, and Single-Minute Exchange of Dies (SMED) [18], to name but a few. The remainder of this paper is organized as follows: the next section discusses a literature review and presents the research hypotheses. Then, Section 3 describes the research methodology, whereas Section 4 discusses the results. Finally, Section 5 concludes with a series of final remarks and industrial implications.

Based on the above issues, there are two main contributions in this research, the first is that using a structural equation model, real and empirical data analyses are used to quantify the relationship between *MAC*, *SUP*, *HRI*, *TTP* with *OBE* gained after a JIT implementation. The relationships between these variables are expressed as measures of dependence between them, which allows managers to focus their efforts on activities that facilitate to obtain the benefits in their own context, excluding those that are trivial. In this sense, this research is-based critical success factor for JIT identified in literature and proposes a causal model that relates them and is not limited only to their identification and description.

The second contribution of this research is that a sensitivity analysis is provided, reporting the conditional probabilities that certain scenarios will occur when latent variables associated with human resources in the JIT execution process have low and high implementation levels and the benefits have been obtained in low and high levels. This analysis allows managers to identify risk attributes that support obtaining a desired benefit and on which they must focus their attention, such as sustainability. It is important to mention that this type of analysis has not been previously reported in studies conducted with causal models in the manufacturing industrial sector.

2. Literature Review and Research Hypotheses

As Singh and Garg [20] point out, worrying about *MAC*, *HRI*, and *TTP* is pointless if companies do not obtain benefits as a result of JIT implementation. According to Iqbal, et al. [21], corporate performance is the result of programs such as TQM and JIT, and top managers are responsible for determining the right implementation strategy for these programs, specifically for human factors and several authors has reported their importance. Table 1 collects a list of papers related to JIT and HR in industry (in this research, JIS is considered to be part of JIT), indicating that there is a direct relationship between them, the SC, and company performance.

Given the importance of HR in JIT implementation, the following paragraphs describe in a more detailed way the role of the manager, the suppliers, the operator integration, and the production tools and techniques used for guaranteeing success.

Table 1. Human resources in JIT implementation success.

Author	Findings
García-Alcaraz, et al. [22]	• JIT is a philosophy based on human resources • Training and investment in incentives are required • JIT increases job satisfaction, teamwork and HR efficiency
Monden [23]	• JIT must have respect for humanity • Human factors guarantee quality and JIT • Suppliers must be certified on quality for prevent productions stoppages.
Bányai and Bányai [24]	• JIS is a supply strategy supported by HR and improve their utilization • JIS is an evolution from JIT and requires HR • JIS must be applied to whole supply chain as a holistic program
Helms, et al. [25] and Oliver [26]	• HR are the most important factor in JIT implementation • Manager must focus in HR for warrantee JIT success
Power and Sohal [27]	• Report a literature review considering HR as an important variable in JIT implementation • JIT is based on HR as philosophy
Power and Sohal [28]	• Report the importance of HR for JIT in Australia • Training and education in HR support JIT and company performance
Yang and Yang [29]	• The Toyota Production System is based on HR, integrated by managers, operators, suppliers and customers.
Lytton, et al. [30]	• JIT as technique support the long-term network among partner in a production system

2.1. Managerial Commitment (MAC) in JIT Implementation

JIT can be implemented in the production process only if managers approve it. For Kumar and Garg [31], top managers are responsible for defining the company's JIT implementation strategy and integrating all the participants into the process, including *SUP* and operators. Similarly, Singh and Garg [20] claim that *MAC* is a key element for JIT systems, and production process engineers must inform managers of the benefits obtainable from JIT. In their work, Montes [32] performed a factor analysis on data gathered from manufacturing companies and found that *MAC* was the most important CSF for successful JIT implementation, since it could be associated with the performance of all the other factors, including *SUP*, employees, and JIT training. Additionally, the authors found that middle managers provided great support to the organizational structure, as they served as the link between top managers and operators.

To measure *MAC*, we relied on the following aspects [17,18,31,33]:

- *MAC1.* Communication and coordination between departments and suppliers.
- *MAC2.* Supervisors promote teamwork by encouraging operators to cooperate and express their opinions.
- *MAC3.* Managers, engineers, and operators frequently interact among them.
- *MAC4.* Senior management culture promotes timely compliance of projects.

2.2. Suppliers (SUP)

The flow of materials in a SC is only guaranteed with the involvement of *SUP*, who are responsible for delivering the raw materials to the manufacturer and keeping JIS in the production lines, avoiding delivery delays [34]. In this sense, delivery times are important, since supply delivery delays automatically trigger both production delays and late final product deliveries. It is thus known that *SUP* must be fully integrated in the SC, and this task is a managerial responsibility [35]. Similarly, having reliable *SUP* reduces uncertainty in the supply process [36], which is why managers must attempt to maintain long-term contracts with trusted, certified *SUP* [37].

To measure *SUP* integration in a JIT implementation environment, the following elements are assessed [20,31,32,38]:

- *SUP1. SUP* are integrated in the company using a pull strategy.
- *SUP2. SUP* deliver raw materials on time.
- *SUP3.* The manufacturing company holds long-term contracts with its *SUP*.
- *SUP4. SUP* are certified.
- *SUP5.* The company relies on a reduced number of *SUP*.

Since several *Supplier*-related activities depend on *MAC*, the first research hypothesis states as follows:

H1. *Managerial Commitment has a positive direct effect on Suppliers in the JIT implementation process.*

2.3. Human Resources Integration (HRI)

Line production supervisors and operators play a key role n the implementation of the JIT philosophy. Researchers such as García, Rivera, Blanco, Jiménez and Martínez [18] found that both training and skills development increased operator empowerment during the JIT implementation process, and Bányai, et al. [39] indicated the importance of human resource strategy for JIS, maintaining material flow along the SC; however, the allocation of resources necessary to these training programs depends on managers [40]. In this sense, senior managers must prioritize training projects focused on employee multifunctionality as an strategy [41]. Moreover, it has been found that investing in human resources training has a positive effect on SC flexibility and agility [42], and thus on the implementation of JIT keeping JIS in production lines.

However, as experts point out, companies should also promote job rotation to increase motivation among employees and offer them new challenges, where they can develop new skills and support waste reducing, but also, for increase the JIS and reducing buffers between work stations [24,39]. Likewise, as Esmaeilian, et al. [43] claim, managers must encourage teamwork during the JIT implementation process, especially during decision-making and problem-solving processes, to preserve support material flow in a JIS.

To measure *HRI* in JIT implementation, the following items are analyzed [20,31,32]:

- *HRI1.* Human resources are trained in multifunctional tasks.
- *HRI2.* The company has a job rotation program.
- *HRI3.* Employees are hired because of their problem solving and teamwork skills.
- *HRI4.* The company has specific work teams to solve production-related problems.
- *HRI5.* Employees are rewarded when they learn new skills.
- *HRI6.* Employees suggest solutions to machine and equipment problems.

Since most *HRI* tasks depend on *MAC*, the second research hypothesis can be proposed as follows:

H2. *Managerial Commitment has a positive direct effect on Human Resources Integration in the JIT implementation process.*

2.4. Production Tools and Techniques (TTP)

JIT is not an isolated technique, but is rather implemented along with other lean manufacturing techniques that help ensure a continuous flow of materials along the production system. To measure this construct, the following items are considered [16,19,20,31,33]:

- *TTP1.* The plant is organized in manufacturing cells or technology groups.
- *TTP2.* Machines are small, flexible, and can be moved.
- *TTP3.* The company has a Kanban system for control production.
- *TTP4.* The company implements a Poka-Yoke system for error prevention.
- *TTP5.* Both JIT and MRP are used for production planning and control.

- *TTP6.* The production program is leveled.
- *TTP7.* The product manufacturing flow is continuous within the value chain.
- *TTP8.* Processes are standardized.

Implementing these techniques requires extensive commitment, both inside and outside of the company. For instance, plant layout depends on what managers decide is best [44], whereas Material Requirements Planning (MRP) is usually implemented along JIT—and again, the top management department decides how many resources will be allocated to such a project [45]. As for Kanban-JIT implementation plans, they are generally a decision of production managers and senior managers [46]. In other words, the *TTP* being implemented in a given production system are subjected to managerial decisions. In this sense, the third research hypothesis can read as follows:

H3. *Managerial Commitment has a positive direct effect on Production Tools and Techniques in the JIT implementation process.*

As Iqbal, Huq and Bhutta [21] claim, well-integrated *SUP* contribute to an effective pull system, thereby increasing both SC flexibility/agility and product quality. Moreover, David and Eben-Chaime [47] found that *SUP* play a key role in manufacturing standards, which is why supplier-manufacturer relationships must be close and direct, and the number of trusted *SUP* should be as reduced as possible. Furthermore, *SUP* must be integrated in the manufacturer's MRP system to simplify real-time information sharing and decision making processes [48]. From this perspective, it can be argued that *TTP* can be associated with *SUP*, making it possible to propose the fourth research hypothesis as follows:

H4. *Suppliers have a positive direct effect on Production Tools and Techniques in the JIT implementation process.*

Successful *TTP* do not emerge overnight. In their research, conducted in the aerospace industry, Martínez-Jurado, et al. [49] found that human resources were the cornerstone of lean manufacturing plans and projects. Such findings are consistent with those reported by Jabbour, et al. [50], who qualitatively explored the relationship between human resources and the implementation of lean manufacturing tools in the automotive industry. In conclusion, since a good *HRI* is associated with the success of *TTP*, the fifth research hypothesis can be proposed as follows:

H5. *Human Resources Integration has a positive direct effect on Production Tools and Techniques in the JIT implementation process.*

2.5. Operational Benefits of JIT (OBE)

It would be useless to allocate time and resources to implement particular *TTP* if they did not bring any benefits in production systems. In their work, Kumar and Garg [31] reported a list of JIT benefits identified in Indian manufacturing companies, whereas Maiga and Jacobs [16] discussed the main effects of JIT on corporate performance. Likewise, other studies have explored JIT benefits in industrial manufacturing companies [9,32].

This research focuses particularly on the *OBE* that can be gained from successful JIT implementation. To assess this construct, the following items are measured [16,19,20,31,32]:

- *OBE1.* Raw material inventory levels decrease.
- *OBE2.* Work in process (WIP) inventory levels decrease.
- *OBE3.* Finish product inventory levels decrease.
- *OBE4.* Inventory turnover increases.
- *OBE5.* Lead times are shorter.
- *OBE6.* Production flexibility increases.
- *OBE7.* Waste levels decrease.

This list of JIT benefits can be attractive to many managers, whose responsibility thus becomes to promote the implementation of a JIT system and monitor its progress and further evolution into tools such as Seru, popularly implemented in Japan for line balancing [51]. However, such evolutions only occur once a given JIT system has reached a maximum level of maturity and thus offers the expected benefits. In this sense, Singh and Garg [20] argue that top management is the cornerstone of JIT maturity. Consequently, the sixth research hypothesis can be formulated as follows:

H6. *Managerial Commitment has a positive direct effect on Operational Benefits in the JIT implementation process.*

Many studies acknowledge the role of *SUP* in operational performance, yet few of them introduce JIT as the mediating variable. Experts argue that top management departments must select *SUP* that support the company's production strategy. This involves taking into account attributes such as quality certifications and commitment [52], compliance with delivery times [35], and sustainability, among other things [38]. Additionally, as Mendoza-Fong, et al. [53] claim, *SUP* must comply with specific attributes to contribute to the implementation of a solid JIT system. In other words, JIT implementation is not feasible without the support of *SUP*, since they are the start of the supply chain, as Shnaiderman and Ben-Baruch [35] state, but can also be a source of risk for SC [54]. Following this discussion, the seventh research hypothesis can be formulated as follows:

H7. *Suppliers have a positive direct effect on Operational Benefits in the JIT implementation process.*

HRI is at the core of the JIT philosophy and its benefits. In their work, García, et al. [55] developed a structural equations model and demonstrated that human resources training and education are associated with corporate performance. Additionally, García-Alcaraz, Macías, Luevano, Fernández, López and Macías [9] found that JIT benefits reflect on human resources, who expect some type of reward for their efforts in the implementation and maintenance of the philosophy. Finally, in their literature review, Singh and Garg [20] placed human factors as the top element for JIT implementation, which is consistent with what authors Kumar and Garg [31] reported in their work. From this perspective, our eighth research hypothesis is proposed below:

H8. *Human Resources Integration has a positive direct effect on Operational Benefits in the JIT implementation process.*

JIT benefits are also the result of the *TTP* implemented within manufacturing companies. In this sense, Ho and Chang [45] and Wang, Gong and Wang [48] found a relation between JIT implementation and MRP implementation, whereas Rodríguez-Méndez, et al. [56] associated JIT with SMED and maintenance systems. Similarly, to Cua, McKone and Schroeder [14], JIT goes hand in hand with quality systems and maintenance systems. Finally, Hou and Hu [6] developed a genetic algorithm to integrate Kanban with JIT, while Abdul-Nour, et al. [57] studied the JIT-Kanban relation and associated it with economic lot size. Following this discussion, the ninth hypothesis of this research is proposed as follows:

H9. *Production Tools and Techniques have a positive direct effect on Operational Benefits in the JIT implementation process.*

Figure 1 depicts the variables analyzed in this research along with their corresponding interrelations, illustrated as hypotheses. In the figure, variable *MAC* is the independent variable, whereas *OBE* is the dependent variable.

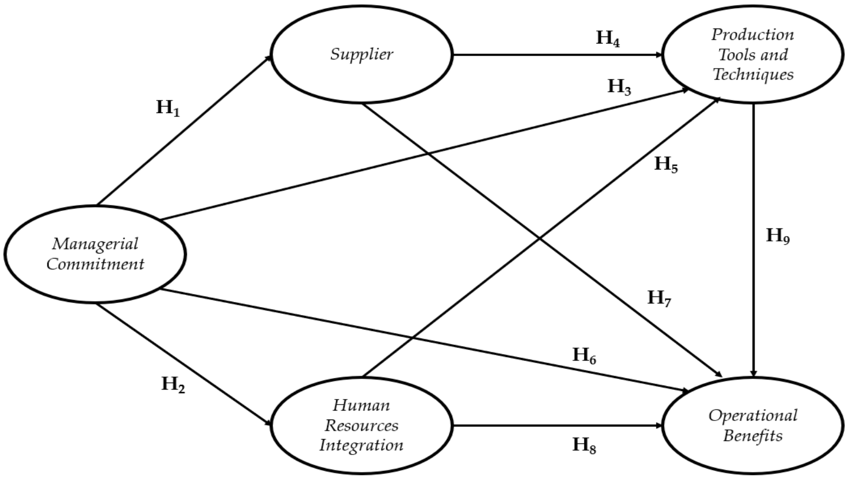

Figure 1. Proposed model.

3. Materials and Methods

The goal of this research is to relate human factor variables and JIT techniques with *OBE* through a structural equation model. To this end, we collected data from the manufacturing industry to determine the relationships between latent variables and test the model validity and reliability. This section discusses the materials and methods employed to reach our goal.

3.1. Questionnaire Design and Administration

A questionnaire is designed to study the latent variables proposed in Figure 1. To identify the items or observed variables that would allow us to assess each latent variable, a literature review is conducted. This stage represented the questionnaire's rational validation process. Then, the draft questionnaire is validated by scholars and regional industrial managers, who answered each question or item using a five-point Likert scale. The final survey was aimed at managers, production supervisors, and JIT implementation engineers. To select the sample, first a stratified sampling method was applied on potential participants who had at least one year of experience in JIT implementation. Then, the snowball sampling method was used when responders recommend other colleagues, increasing the sample's size. Please check the applied questionnaire, which appears as Supplementary Material 1.

3.2. Data Capture, Screening, and Descriptive Analysis

The software program SPSS 24® is used to capture the information collected via the questionnaires [58]. Then, then the following screening tasks are performed on the database to avoid biased results:

- Identify missing values: the identified missing values are replaced by the median value. However, questionnaires with more than 10% missing values are removed from the analysis.
- Identify outliers: the identified outliers are replaced by the median value, since they directly affect the parameter estimation process.

Finally, a descriptive analysis is performed for each latent variable, thereby obtaining a median value—as a measure of central tendency—and interquartile range value (i.e., the difference between first quartile and third quartile)—as a measure of data dispersion [58].

3.3. Data Validation

Before testing the model, six coefficients are estimated to validate the five latent variables depicted in Figure 1:

- R-Squared (R^2) and adjusted R-Squared (Adj. R^2) as indicators of parametric predictive validity. Values higher than 0.2 are necessary [59].
- Q-Squared (Q^2) as an indicator of non-parametric predictive validity. Values greater than 0 and similar to their corresponding R^2 values are necessary [60].
- Composite reliability index and Cronbach's alpha index as indicators of internal validity. Values higher than 0.7 are sought [61].
- Average Variance Extracted (AVE) as a measure of discriminant validity. Values higher than 0.5 are sought [62].
- Variance Inflation Factors (VIFs) as a measure of collinearity. Values lower than 3.3 are sought. However, the squared correlations between the latent variables is used for detecting multicollinearity and test discriminant validity, showing on diagonal the squared root of AVE [63].
- Also, factor cross loadings are analyzed to determine convergent validity of items into latent variables. Values higher than 0.5 are sought [64].

3.4. Model Evaluation

The model illustrated in Figure 1 is tested using the structural equations modeling (SEM) technique based on partial least squares (PLS) and integrated in WarpPLS 6® software program, which is recommended for ordinal, non-normal data and small samples [65], and similar research has been performed using these techniques, such as, for example, Díaz-Reza, et al. [66], who related the SMED stages to the benefits gained, and Boon Sin, et al. [67], who reported the relationship between knowledge management and six sigma success. The indices and parameters for model validation were obtained with a 95% confidence level. The following model fit and quality indices were estimated [68]:

- Average Path Coefficient (APC) and a p value lower than 0.05 is required.
- Average R-Squared (ARS) and Average Adjusted R-Squared (AARS) as indicators of predictive validity, and p values lower than 0.05 are required.
- Average block VIF (AVIF) and Average Full collinearity VIF (AFVIF) as a measure of multicollinearity. A value lower than 3.3 is required.
- Tenenhaus Goodness of Fit (GoF) Index to measure model fit. A value higher than 0.36 is necessary.

3.4.1. Direct Effects and Effect Sizes

In structural equation models, direct effects measure the relationship between two latent variables. They are usually depicted as arrows and help validate research hypotheses, such as those depicted in Figure 1. The magnitude of each effect is estimated using the beta (β) coefficient, which indicates in standard deviations how much a dependent latent variable varies as its corresponding independent latent variable increases or decreases by one unit. For all the effects, the corresponding confidence interval is estimated at 95%.

Finally, all the dependent latent variables are associated with an R^2 value as a measure of explained variance on it. The R2 coefficient indicates the percentage of variance in a dependent variable that can be explained by one or more independent variables. If two or more independent variables are responsible for the variability of a dependent latent variable, the R^2 value must be decomposed into effect sizes (ES).

3.4.2. Sum of Indirect Effects and Total Effects

The hypotheses depicted in Figure 1 represent direct effects; however, a relationship between two latent variables can also occur using one or more mediating variables. In this sense, indirect effects link two latent variables through two or more segments or model paths. This research only reports the sum of the indirect effects for each relationship with a 95% confidence interval. Finally, the total effects (i.e., sum of direct and indirect effects in a relationship between two latent variables) were also calculated, and each indirect and total effect value is associated with a *p* value—as an indicator of statistical significance—and an ES value.

3.4.3. Sensitivity Analysis

Managers really want to know what will happen if they have some situation, such as, for example, poor relationships with *SUP*, and how that will affect the possible benefits offered by JIT. To address this, a sensibility analysis is reported with different scenarios for the model's latent variables; since these are standardized values, the conditional probabilities can be estimated. For every research hypothesis proposed in Figure 1, the following aspects are estimated:

- The probability of a variable occurring on a lower or higher level independently; that is, $P(Z < -1)$ and $P(Z > 1)$, respectively.
- The probability of each variable occurring simultaneously in its multiple possible combinations. This probability is represented by *&*, and the combinations are: $P(Z_i > 1)$ and $P(Z_d > 1)$, $P(Z_i > 1)$ and $P(Z_d < -1)$, $P(Z_i < -1)$ and $P(Z_d > 1)$, $P(Z_i < -1)$ and $P(Z_d < -1)$.
- The probability of the occurrence of a dependent latent variable on a certain level with respect to the variability of an independent latent variable. This is a conditional probability expressed using the word *If*. For each research hypothesis, four possible combinations were found: $P(Z_i > 1/Z_d > 1)$, $P(Z_i > 1/Z_d < -1)$, $P(Z_i < -1/Z_d > 1)$ and $P(Z_i < -1/Z_d < -1)$.

The sensitivity analysis makes it possible to further explore the risks/benefits of having either low or high levels in the latent variables. Namely, $P(Z_i)$ represents the probability of an independent variable in a given level, whereas $P(Z_d)$ stands for the probability of a dependent variable. Finally, in sensitivity analyses, the plus (+) and minus symbols (−) are used to indicate high and low values in the latent variables, respectively. For instance, *MAC*+ indicates a high level of *MAC*, whereas *SUP*− indicates a low level in *SUP*.

4. Results

This section comprises three subsections that respectively discuss the results obtained from the sample's descriptive analysis, the item's descriptive analysis, and the model's assessment.

4.1. Sample Characterization

The survey was administered for three months (June–August 2019) in Mexican manufacturing companies located in Ciudad Juarez, Chihuahua. In total, 352 valid questionnaires were collected, 104 of which had been answered by female and 248 by male participants. As for the job positions, the sample was formed of 178 production system engineers, 153 production supervisors, and 21 managers. Table 2 summarizes the results regarding the surveyed industries and the sample's length of field experience. As can be observed, the automotive, medical, and electrical industries are the most prominent.

Table 2. Surveyed industries and length of experience (years).

Industry	Years of Experience				Total
	1–2	2–5	5–10	>10	
Automotive	41	72	24	21	158
Medical	17	42	19	8	86
Electrical	7	25	12	11	55
Electronics	5	19	9	18	51
Aerospace	1	1	0	0	2
Total	71	159	64	45	352

4.2. Descriptive Analysis and Validation of Items

Table 3, below, summarizes the results from the descriptive analysis of the items included in the latent variables. The items appear ranked in descending order according to their median values. In this sense, it is found that in terms of *MAC*, interdepartmental communication and coordination is the most important aspect, along with a culture of compliance. As for *HRI*, the analysis revealed that both employee training/education and job rotation are the most valuable. These aspects help manufacturing companies have multifunctional employees, which consequently can improve the material flow. With respect to *TTP*, Poka-joke systems are the most important, since they prevent errors from being propagated along the production system. Moreover, Poka-joke systems help to standardize production processes. As regards *SUP*, findings reveal that quality certificates and long-term contracts are essential, and thus appear as indicators of *Supplier* reliability. Finally, in terms of *OBE*, JIT reduces final product delivery times (a basic quality principle), waste, and inventory levels of both raw materials and work in progress.

Table 3. Item descriptive analysis and convergent validity test.

Latent Variable/Item	Median	IQR
MAC1	4.20	1.584
MAC2	4.11	1.58
MAC3	3.94	1.587
MAC4	3.71	1.608
HRI1	3.85	1.647
HRI2	3.73	1.754
HRI4	3.67	1.71
HRI6	3.43	1.837
HRI3	3.39	1.9
HRI5	3.18	1.917
TTP4	4.09	1.578
TTP8	4.08	1.563
TTP3	4.05	1.775
TTP5	3.89	1.651
TTP7	3.88	1.476
TTP1	3.85	1.619
TTP6	3.62	1.626
TTP2	3.4	1.928
SUP4	4.12	1.59
SUP3	3.93	1.569
SUP2	3.84	1.587
SUP1	3.66	1.832
SUP5	3.55	1.741
OBE5	3.91	1.513
OBE7	3.86	1.675
OBE1	3.77	1.537
OBE2	3.75	1.516
OBE6	3.73	1.67
OBE3	3.71	1.648
OBE4	3.68	1.581

Table 4 lists the coefficients estimated to test the validity of the latent variables. According to these results, all the latent variables have enough parametric and non-parametric validity, since all the R^2, adjusted R^2, and Q^2 values are higher than 0.2. Likewise, no internal collinearity problems are found in the latent variables, since all the VIF values are lower than 3.3. Finally, the Cronbach's alpha and composite reliability values indicate that the five latent variables have enough internal validity (i.e., the values are higher than 0.7).

Table 5 indicates the cross loadings for items in latent variables, indicating that there is an adequate discriminant validity because all they are higher than 0.5, the minimum cut-off admissible in this research.

Table 4. Latent variable coefficients.

Index	Latent Variable				
	HRI	*MAC*	*SUP*	*TTP*	*OBE*
R^2	0.251		0.265	0.626	0.547
Adjusted R^2	0.249		0.263	0.623	0.542
Composite reliability	0.864	0.872	0.862	0.896	0.923
Cronbach's alpha	0.811	0.804	0.799	0.867	0.903
Average variance extracted	0.516	0.631	0.557	0.519	0.634
Variance inflation factor	1.664	1.636	2.164	3.153	2.169
Q^2	0.251		0.266	0.625	0.547

Table 5 indicates the cross loadings for items in latent variables, indicating that there is an adequate discriminant validity. Observe that italic cross loading values, associated to every latent variable, are the highest in their row. Finally, Table 6 indicates the correlation among latent variables and values indicates absence of multicollinearity and adequate discriminant validity. Observe that bold values, associated to latent variable, are the highest in their column and row. Please check Supplementary Material 2 for *t* values associated with cross loadings and their confidence interval.

Table 5. Cross loadings.

Ítems	Latent Variables				
	HRI	*MAC*	*SUP*	*TTP*	*OBE*
HRI1	*0.66*	0.22	−0.31	0.315	−0.016
HRI2	*0.659*	−0.113	−0.042	0.234	0.051
HRI3	*0.765*	−0.05	0.077	−0.188	−0.065
HRI4	*0.731*	−0.064	−0.123	−0.009	0.054
HRI5	*0.645*	0.194	0.126	−0.103	0.016
HRI6	*0.69*	−0.178	0.254	−0.097	−0.024
MAC1	−0.115	*0.714*	−0.039	0.078	−0.032
MAC2	0.021	*0.737*	0.13	−0.237	−0.033
MAC3	0.165	*0.688*	−0.031	−0.106	0.032
MAC4	−0.041	*0.625*	−0.089	0.333	0.058
SUP1	0.026	−0.103	*0.613*	0.237	0.139
SUP2	−0.011	−0.086	*0.678*	0.094	−0.106
SUP3	0.005	0.045	*0.687*	−0.116	−0.091
SUP4	−0.121	0.169	*0.644*	0.17	−0.108
SUP5	0.111	−0.031	*0.653*	−0.385	0.241
TTP1	0.191	−0.111	−0.098	*0.613*	−0.076
TTP2	0.226	−0.305	−0.018	*0.624*	−0.001
TTP3	−0.075	−0.188	−0.036	*0.659*	−0.083
TTP4	−0.062	0.194	−0.148	*0.599*	0.035
TTP5	−0.163	−0.042	0.015	*0.618*	0.121
TTP6	0.033	0.268	−0.109	*0.571*	0.356
TTP7	−0.02	0.174	0.178	*0.592*	−0.02
TTP8	−0.089	0.185	0.197	*0.605*	−0.208
OBE1	−0.011	0.098	−0.153	0.022	*0.659*
OBE2	−0.034	0	0.065	−0.058	*0.652*
OBE3	−0.065	0.086	−0.154	0.11	*0.654*
OBE4	0.087	−0.166	0.152	−0.071	*0.646*
OBE5	−0.147	0.091	0.002	0.177	*0.631*
OBE6	0.059	−0.097	0.042	−0.067	*0.658*
OBE7	0.135	−0.044	0.105	−0.125	*0.636*

Table 6. Squared correlations between latent variables (with AVE on the diagonal).

Latent Variables	Latent Variables				
	HRI	*MAC*	*SUP*	*TTP*	*OBE*
HRI	***0.718***	0.499	0.468	0.592	0.508
MAC	0.499	***0.794***	0.506	0.557	0.518
SUP	0.468	0.506	***0.746***	0.518	0.584
TTP	0.592	0.557	0.518	***0.72***	0.701
OBE	0.508	0.518	0.584	0.701	***0.796***

4.3. Model Testing

Figure 2 depicts the structural equation model already evaluated. Every relationship among the latent variables is associated with a β value as a measure of dependency and a *p*-value as an indicator of statistical significance. Since all the *p*-values are lower than 0.05, it is concluded that all the direct effects proposed by the hypotheses are statistically significant at a 95% confidence level. For instance, as regards the first hypothesis (H_1), there is enough statistical evidence to confirm that *MAC* has a positive direct effect on *SUP* in a JIT implementation process, since when the former increases by one standard deviation, the latter increases by 0.515 standard deviations. Similar interpretations can be formulated for the remaining hypotheses. Please check Supplementary Material 2 for detailed *t* values associated with β values and their confidence intervals.

Table 7 summarizes the conclusions about the hypotheses according to the *p*-values associated with β.

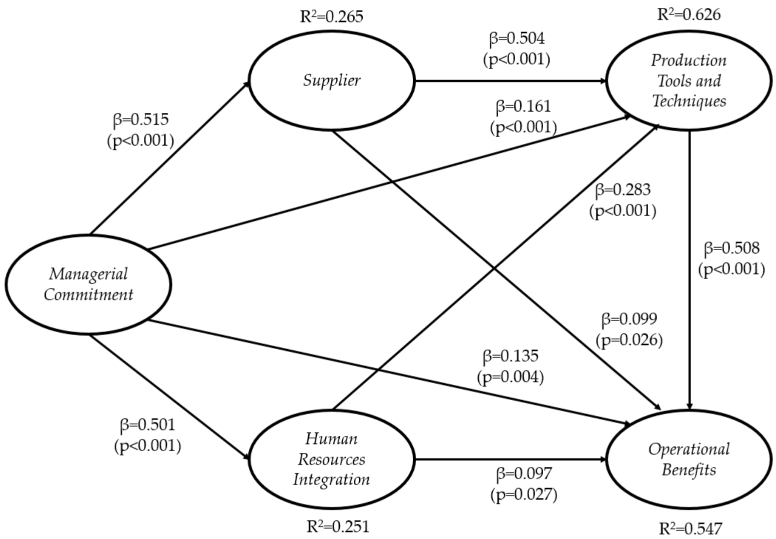

Figure 2. Evaluated model (validation of hypotheses).

Table 7. Hypothesis validation results.

H_i	Independent Variable	Dependent Variable	β Value (*p*-Value)	Conclusion
H1	*MAC*	*SUP*	0.515 ($p < 0.001$)	Accepted
H2	*MAC*	*HRI*	0.501 ($p < 0.001$)	Accepted
H3	*MAC*	*TTP*	0.161 ($p < 0.001$)	Accepted
H4	*SUP*	*TTP*	0.504 ($p < 0.001$)	Accepted
H5	*HRI*	*TTP*	0.283 ($p < 0.001$)	Accepted
H6	*MAC*	*OBE*	0.135 ($p = 0.004$)	Accepted
H7	*SUP*	*OBE*	0.099 ($p = 0.026$)	Accepted
H8	*HRI*	*OBE*	0.097 ($p = 0.027$)	Accepted
H9	*TTP*	*OBE*	0.508 ($p < 0.001$)	Accepted

Table 8 summarizes the results after decomposing the R^2 value in every dependent latent variable. The goal at this stage is to determine which independent variable is more important to a dependent variable to which it is related. In this sense, *OBE* (dependent latent variable) is 54.7% explained by four independent latent variables, among which *TTP* is the most important because its contribution to the R^2 value is higher (ES = 0.365 or 36.5%). In turn, the most important variable to explain *TTP* is *SUP* (ES = 0.365 or 36.5%).

Table 8. Effect sizes (ES) for direct effects.

Dependent Variable	Independent Variable				R^2
	HRI	***MAC***	***SUP***	***TTP***	
HRI		0.251			0.251
SUP		0.265			0.265
TTP	0.169	0.092	0.365		0.626
OBE	0.051	0.072	0.059	0.365	0.547

Table 9 lists both the sum of indirect effects and the total effects found in the relationships. Every effect is associated with a β value, a *p*-value as the indicator of statistical significance, and an ES value. Such results help to understand the relationships between two variables that, at first glance, seemed to have little or no significant connection. For instance, the direct effect of *MAC* on *TTP* is only 0.161 units, yet the sum of their indirect effects is equal to 0.401 units. In the end, the relationship between *MAC* and *TTP* has the highest total effects—i.e., 0.562 units. A similar phenomenon occurs in the relationship between *MAC* and *OBE*, where the indirect effect is higher than the direct effect.

Table 9. Sum of indirect effects and total effects.

	Sum of Indirect Effects			
Dependent Variable	**Independent Variable**			
	HRI	***MAC***	***SUP***	***TTP***
TTP		0.401($p < 0.001$) ES = 0.229		
OBE	0.144 ($p < 0.001$) ES = 0.074	0.386 ($p < 0.001$) ES = 0.207	0.256 ($p < 0.001$) ES = 0.151	
		Total Effect		
HRI		0.501 ($p < 0.001$) ES = 0.251		
SUP		0.515 ($p < 0.001$) ES = 0.265		
TTP	0.283 ($p < 0.001$) ES = 0.169	0.562 ($p < 0.001$) ES = 0.321	0.504 ($p < 0.001$) ES = 0.365	
OBE	0.242 ($p < 0.001$) ES = 0.125	0.521 ($p < 0.001$) ES = 0.279	0.355 ($p < 0.001$) ES = 0.210	0.508 ($p < 0.001$) ES = 0.365

Table 10 introduces the findings from the sensitivity analysis. The table indicates the probability of each latent variable to lie at a high or low level independently, conjointly, or conditionally. For instance, *MAC* is more likely to lie at a high level (*MAC*+) independently than to lie at a low level (*MAC*+). Consequently, the likelihood of *Supplier* levels being high (*SUP*+) is greater if *MAC* levels are high (*MAC*+). Conversely, low *MAC* levels (*MAC*−) imply greater risks (i.e., 0.397) of having low levels in *SUP* (*SUP*−). In conclusion, if there is little likelihood of having high *Supplier* levels due to low levels in *MAC*, top managers must be particularly careful with and attentive to the company's relationship with its *SUP* in the JIT implementation process.

Table 10. Sensitivity analysis results.

				Independent Latent Variables							
				MAC		***SUP***		***HRI***		***TTP***	
				+	−	+	−	+	−	+	−
				0.161	**0.169**	**0.159**	**0.153**	**0.175**	**0.159**	**0.169**	**0.156**
Dependent latent variables	*SUP*	+	0.159	&0.056 *If* 0.350	&0.008 *If* 0.048						
		−	0.153	&0.005 *If* 0.033	&0.067 *If* 0.397						
	HRI	+	0.175	&0.065 *If* 0.400	&0.005 *If* 0.032	&0.062 *If* 0.390	&0.000 *If* 0.000				
		−	0.159	&0.013 *If* 0.083	&0.067 *If* 0.397	&0.013 *If* 0.085	&0.059 *If* 0.386				
	TTP	+	0.169	&0.067 *If* 0.417	&0.005 *If* 0.032	&0.081 *If* 0.508	&0.000 *If* 0.000	&0.086 *If* 0.492	&0.005 *If* 0.034		
		−	0.156	&0.011 *If* 0.067	&0.073 *If* 0.429	&0.000 *If* 0.000	&0.097 *If* 0.630	&0.003 *If* 0.015	&0.081 *If* 0.508		
	OBE	+	0.148	&0.046 *If* 0.283	&0.008 *If* 0.048	&0.062 *If* 0.390	&0.003 *If* 0.018	&0.059 *If* 0.338	&0.008 *If* 0.051	&0.086 *If* 0.508	&0.003 *If* 0.017
		−	0.140	&0.008 *If* 0.050	&0.056 *If* 0.333	&0.003 *If* 0.017	&0.067 *If* 0.439	&0.008 *If* 0.046	&0.067 *If* 0.424	&0.000 *If* 0.000	&0.089 *If* 0.569

5. Discussion: Industrial and Managerial Implications

This research integrates five latent variables in a structural equation model to assess their interrelations and effects in the JIT implementation process. Our research findings and their implications can be discussed as follows:

- *MAC* is the key to JIT implementation in production systems [48], since it has the highest positive direct effects on the remaining variables. Because managers make the final decisions, they have to be the most involved in the JIT implementation process, especially in aspects that involve *HRI* and a company's relationship with its *SUP*.
- *MAC* has a positive direct impact on *TTP*. Considering that managers ultimately decide what *TTP* are implemented in a production system, the value of the direct effect is relatively low (β = 0.161). However, after analyzing the indirect effects (β = 0.401) that occur thanks to mediating variables *SUP* and *HRI*, we found that the relationship between *MAC* and *TTP* is much more important, since the total effects are β = 0.562. Such results imply that managers need support from both operators and *SUP* to implement *TTP*, who can train operators in the use of specific production techniques. This claim is consistent with that of Shnaiderman and Ben-Baruch [35].
- The direct effect of *MAC* on *OBE* is only β = 0.135; however, after analyzing the indirect effects that occur thanks to *SUP*, *HRI*, and *TTP* (β = 0.386), we found that the total effects in this relationship are β = 0.521. These results imply once more that JIT benefits can be obtained only if managers plan the JIT implementation process carefully, by properly integrating human resources (including *SUP*) and production machinery, techniques, and methodologies [9].
- *Human Resources* that are well integrated in production tools, namely lean manufacturing tools, are a key element in obtaining the desired *OBE* [68]. In this research, we found a relatively low positive direct effect from *HRI* on *OBE* (i.e., β = 0.097). However, the relationship is much more important when taking into account the indirect effects that occur through *TTP* (β = 0.144); that is, the total effects in the relationship between *HRI* and *OBE* report β = 0.242. These results demonstrate that operator knowledge, experience, and skills must be applied in *TTP*. Consequently, managers must promote collaborative work environments and the development of multifunctional skills, which would contribute to a correct material flow.
- *SUP* may be external entities, yet they do have an impact on the *OBE* that companies gain by implementing a JIT system. *SUP* are important since they supply manufacturers with raw materials, machinery, and equipment. The direct relationship between *SUP* and *OBE* has a low but still significant value of β = 0.099; however, the indirect effects caused by *Production Tools and*

Technologies have a value of β = 0.256. In total, the relationship has a value of β = 0.355, which reveals that managers must be attentive to the technological innovations that *SUP* can offer them to improve the production flow along the system. This is where improvements can be made by proposing new production techniques.

- Direct and indirect effects are interesting, yet it is also important to analyze the performance of the latent variables under certain conditions. In this sense, the implications of the sensitivity analysis performed on the latent variables (see Table 8) can be discussed as follows:
- High levels of *MAC* are essential for the performance of all the other variables. *MAC*+ increases the likelihood of *SUP*+ by 0.350, that of HRI+ by 0.400, the likelihood of TTP+ by 0.470, and that of OBE+ by 0.283. Conversely, low *MAC* levels (*MAC*−) increase the risks of both *SUP*− and *HRI*− by 0.397, those of TTP− by 0.429, and the risks of OBE− by 0.333.
- *SUP* are external entities; however, as the first supply chain system component, they can facilitate the JIT implementation process. High levels in *SUP* (i.e., *SUP*+) increase the likelihood of *HRI*+ by 0.390 and that of *TTP*+ by 0.508, which is a value much higher than that of *MAC*+. Similarly, *SUP*+ increases the likelihood of OBE+ by 0.390. On the other hand, low *Supplier* levels (i.e., *SUP*−) imply risks in the other variables. Namely, it is impossible for production systems to rely on well-implemented *TTP*, since the value of *TTP*+ is 0, whereas the value of *TTP*− is 0.630. Likewise, *SUP*− does not guarantee *OBE*+, as the likelihood value is only 0.003, while the risks of *OBE*− increase by 0.439. Such results imply that *SUP* are the supporting base of the JIT implementation process in production systems, which is consistent with what authors Shnaiderman and Ben-Baruch [35] claim.
- Appropriate *MAC* and good relationships with *SUP* do not guarantee the success of JIT on their own. *HRI* is equally important. According to our analysis, *HRI*+ increases the likelihood of *TTP*+ by 0.492 and that of *OBE*+ by 0.338. However, *HRI*- guarantees neither *TTP*+ nor *OBE*+, since the likelihood values are 0.005 and 0.008, respectively. Finally, *HRI*− increases the risks of *TTP*− by 0.508 and those of *OBE*− by 0.424. These results demonstrate that human experience and skills are necessary to successfully implement *Production Tools and Technologies* in production systems, which is consistent with what authors García-Alcaraz, et al. [10] argue.
- Finally, we found that *TTP*+ guarantees *OBE*+ (0.508) and is never associated with *OBE*− (0.000). Nevertheless, *TTP*− cannot guarantee *OBE*+ and increases the risks of *OBE*− by 0.659. In conclusion, JIT must not be isolated from the *Production Tools and Technologies* already implemented in a production system, such as MRP [45,48], TQM y TPM [14,21], and SMED [69], to name but a few.

6. Conclusions, Limitations and Future Research

JIT is a lean manufacturing tool that offers attractive benefits to production systems when it is well implemented. A solid JIT system requires hard work to associate the obtained benefits and generate tangible metrics. Similarly, as a philosophy, JIT depends on both internal human factors (managers, operators) and external human factors (*SUP*) and managers must pay attention to their human resources satisfaction and knowledge. Quantitative findings in this research led to the conclusion that human research is an important factor for JIT implementation success, and it is not an isolated technique, as it must be integrated with all of the other techniques that are already implemented in production systems that support materials flow. For example, Hou and Hu [6] integrated Kanban with JIT using genetic algorithms, and Al-Tahat and Mukattash [46] proposed a new production design for integrating these Techniques.

In relation to the sensitivity analysis performed with conditional probabilities, the following quick conclusions could be obtained:

- High levels on *MAC* provide high levels on *SUP*, *HRI*, *TTP*, and guarantee *OBE*; however, low levels on *MAC* propitiate risks of obtaining low levels for these variables.

- High *SUP* levels promote high levels of *HRI*, *TTP* and *OBE*. In contrast, low *SUP* levels represent a risk for these variables and the entire JIT implementation process.
- High levels on *HRI* facilitate the attainment of high levels of *TTP* and *OBE*, and conversely, low levels of *HRI* pose a risk, as human resources are responsible for implementing JIT.
- Finally, high levels on *TTP* guarantee high levels on *OBE* since they support the JIT philosophy. In the same way, low *TTP* levels are a risk to the JIT implementation process.

However, this research reports the results from a structural equation model that integrates only four independent latent variables or critical success factors associated with JIT and a dependent variable associated with operating benefits, and there are many other variables and benefits associated with JIT. This indicates that the current model is not complete, and that other analyses are required to generate integrative models with greater explanatory power, which can be easily observed in the R^2 values of the dependent variables. They are not totally explained, since they are values lower than one, which can be considered a limitation of this research.

In the same way, this study focuses on the maquiladora industry, which is predominant in the northern region of Mexico and is represented by the automotive and electronics industry sectors; so these results can only be applied to those specific sectors. The above limitations suggest that the following future research should be proposed:

- Apply the survey used in other sectors in order to find differences and effectiveness of the model, since JIT is a tool that can easily be applied in different types of industries, such as hospitality and food services, where customer satisfaction is strongly related to timely delivery.
- Generate an integral and holistic model that makes it possible to incorporate more latent variables and, in this way, increase its explanatory power and the R^2 values for the dependent variables.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/7/1864/s1.

Author Contributions: Different tasks were done in this research by their authors: conceptualization, J.L.G.-A. and A.R.-V.; methodology, J.L.G.-A. and P.G.-A.; validation, E.J.M., M.P.d.l.P., and J.B.F.; formal analysis, J.L.G.-A.; investigation, J.L.G.-A. and P.G.-A.; resources, J.L.G.-A. and M.P.P.; data curation (and data acquisition and analysis), J.L.G.-A. and E.J.M.; writing—original draft preparation, J.L.G.-A. and J.B.F.; writing—review and editing, J.L.G.-A. and A.R.-V.; visualization, J.L.G.-A.; supervision, J.L.G.-A. and M.P.d.l.P.; project administration, P.G.-A.; funding acquisition, J.L.G.-A.

Funding: This research was funded by Mexican National Council for Science and Technology, grant number CONACYT-INS (REDES) 2018-293683 LAS.

Acknowledgments: The authors thank the company managers that allowed their staff to answer the survey. Without their support, this article would not have been possible.

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

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