Hindawi
Complexity
Volume 2017, Article ID 5912940, 10 pages
https://doi.org/10.1155/2017/5912940

Research Article

Interrelations among SMED Stages: A Causal Model

José Roberto Díaz-Reza,[1] Jorge Luis García-Alcaraz,[2] José Roberto Mendoza-Fong,[1] Valeria Martínez-Loya,[2] Emilio Jiménez Macías,[3] and Julio Blanco-Fernández[4]

[1]*Department of Electrical and Computer Sciences, Universidad Autónoma de Ciudad Juárez, Ave. del Charro 450 Norte. Col. Partido Romero, 32310 Ciudad Juárez, CHIH, Mexico*
[2]*Department of Industrial and Manufacturing Engineering, Universidad Autónoma de Ciudad Juárez, Ave. del Charro 450 Norte. Col. Partido Romero, 32310 Ciudad Juárez, CHIH, Mexico*
[3]*Department of Mechanical Engineering, University of La Rioja, Luis de Ulloa 20, Logroño, 26004 La Rioja, Spain*
[4]*Department of Electrical Engineering, University of La Rioja, Luis de Ulloa 20, Logroño, 26004 La Rioja, Spain*

Correspondence should be addressed to José Roberto Díaz-Reza; al164440@alumnos.uacj.mx

Received 2 March 2017; Revised 16 June 2017; Accepted 4 July 2017; Published 3 August 2017

Academic Editor: Carlos Gershenson

Mexico has received a lot of foreign investment that has brought in a wide range of novel production philosophies, such as Single Minute Exchange of Dies (SMED). Despite its popularity and reported effectiveness, Mexican companies often quit SMED implementation as they consider it challenging. This usually happens when organizations are not familiarized enough with each one of the SMED stages or do not know how they are interrelated. In this article the interrelations among the different SMED implementation stages by means of a structural equations model are analyzed. Data for constructing the model were gathered from a survey administered to 250 employees from the Mexican maquiladora industry. The survey assessed the importance of 14 activities belonging to the four SMED stages. The descriptive analyses of these stages were conducted and integrated into a structural equations model as latent variables, to find their level of dependency. The model was constructed using WarpPLS 5 software, and direct, indirect, and total effects among variables are analyzed and validated. Results from the model revealed that Stage 1 of SMED implementation, known as the *Identification Stage*, has both direct and indirect effects on all the other SMED stages, being the most important stage.

1. Introduction

Many companies respond to the globalization phenomenon by establishing subsidiaries abroad, since this technique allows organizations to reach proximity to target markets. In the case of Mexico, subsidiaries are usually known as *maquiladoras* [1], and they belong to global manufacturing networks that work under the attractive benefits offered by the hosts countries. Some of these benefits include available infrastructure, high training levels, and low production costs [1].

The concept of *maquiladoras*, also known as "twin plants" or "shared production," emerged as a new manufacturing operations model originally put forward in the Mexico-United States border during the 1960s [2], although it later became attractive to numerous European and Asian companies [2]. The maquiladora industry thus became a means to supply manufacturing goods to a larger market and a source of employment for the Mexican people [3], and because of its increasing popularity, the Mexican government established regulations that allowed both domestic and foreign-owned companies to temporally import materials and equipment and export finished products under preferential tariff rates [3].

Many parent companies seek to establish maquiladoras in the Mexican territory to benefit mainly from low labor costs, less restrictive unions and regulations, and greater proximity to target markets [4]. Mexico is thus a facilitator to parent countries since Mexican maquiladoras offer competitiveness and proximity to two major markets, the United States and

Canada [5]. In fact, thanks to the North American Free Trade Agreement (NAFTA) signed by these three countries, many enterprises overseas settle subsidiaries in Mexican land to introduce their products to US and Canadian markets [1].

The maquiladora industry has become so important to Ciudad Juárez, a Mexican border city located in the state of Chihuahua. A report issued in October 2016 claims that, of the 5,012 maquiladoras settled in Mexican territory, 322 are located in Ciudad Juárez, thus representing 6.42% of the national maquiladora industry and generating 263,463 direct maquiladora-related jobs.

Maquiladora sector faces two major problems, rapid production flow and quick introduction of new products into the market, as final customers call for shorter delivery times, low costs, high quality, and highly product customization [6]. Likewise, markets can impose additional exigencies, such as small batch production, which eventually leads to unitary production [7]. Such exigencies are not exclusive to a particular industry, since they have become a global phenomenon [8] and as a response to small batch production challenges, approaches such as *lean* and *pull*—which is a customer-oriented system—have emerged as a means to fulfill the needs of customers without compromising production performance [9]. In this sense, companies must ensure shorter setup times and quick changeovers and both processes are considered to be waste, since machineries, equipment, and operators must stop working, which contributes to increasing manufacturing costs [10]. In this sense, time reduction is a responsibility of lean manufacturing, which aims at waste elimination, especially during setup and changeover times [11].

As a response to last problem *Single Minute Exchange of Dies* (SMED) is defined as a theory and a set of techniques that makes it possible to reduce changeover times to the "single" digits, in other words, to less than 10 minutes [12]. SMED is thus approached as a lean manufacturing tool that helps solve the problems caused by constant equipment changeovers; it improves the *setup* process and reduces the time it takes to change a line or machine from running one product to the next. In fact, setup/changeover time reductions through SMED can reach up to 90% under moderate investments [13]. SMED thus allows companies to respond to market fluctuation, minimize delivery times, reduce waste in setups, and, ultimately, achieve small batch production [14].

1.1. Research Problem and Objective. SMED is a technique widely used by maquiladora companies that is requiring to produce different products in small batches, which forces them to make constant changes in their production lines, making fast setups in machinery to meet these new production orders. Unfortunately, SMED implementation in maquiladoras seldom yields the expected results, and thus companies often quit its application.

Poor results from SMED implementation may appear either because companies are not familiarized enough with the conceptual stages of SMED, or because they do not know how such stages are interrelated; consequently, it is impossible to correctly associate SMED activities with the obtained results or benefits to prioritize the critical operations. To solve this problem, in this article the main research objective is to identify the critical success activities of SMED in the maquiladora industry of Ciudad Juárez. Then, using a structural equations model, we find and quantify the relationships existing among these activities grouped in stages. Results are aimed to support decision makers in the process of identifying key SMED implementation activities and removing unnecessary ones, and this would allow maquiladoras to obtain the expected results.

2. Literature Review and Hypotheses Development

2.1. Literature Review. Companies implement SMED because they can gain certain benefits. Among the SMED benefits reported in the literature, Musa et al. [11] highlighted changeover times minimization and increasing productivity. In this sense, results of their research revealed that *setup* times could be reduced up to 70% thanks to SMED implementation. Similarly, in their study, Ribeiro [15] summarized benefits gained from applying SMED methodology in the production process of plastic and metal components required for the assembly of several kinds of circuit breakers. Beyond the visible economic and technical benefits, authors reported that SMED practices enhanced ergonomic conditions of workstations, achieved setup time reductions ranging from 59% to 90%, and minimized work in process (WIP) of the metal components from 17.05 to 7.74 days, thereby reducing more than 50% of the corresponding costs. In addition, the study states that SMED implementation allowed for WIP cost reduction of over 80% and dramatic minimization of the distance travelled by operators during the changeover process, from 300 m. to 10 m. and less.

Bandyopadhyay [16] reported the impact of SMED on a small-scale automotive industry, where they found that the methodology allowed for 30% of cost reduction and 97 seconds of setup times minimization, thus increasing productivity. Likewise, Yashwant and Inamdar [17] proved that SMED increased utilization rate of four machines that originally worked at a speed 80% below their capacity; in this sense, SMED managed to reduce 50% of setup times and increased production flexibility. Finally, Berk [18] tested SMED applications at two bottleneck setup operations: cast on trap and heat seal. The experiments achieved substantial reduction of cast on trap setup time to 54% and heat seal setup time to 47% as well as significant cost savings at the company level in the assembly lines.

2.2. The SMED Methodology. Previously, SMED was defined as a methodology, and then there are some stages on it. In his work, Shingo [12] presented the four conceptual stages of SMED implementation that make it possible to reduce *setup* and/or changeover times. At the preliminary or zero stage, internal and external work is not yet distinguished, yet Shingo recommends starting by examining the productive process by conducting a continuous production analysis and a work sampling study. It is also advised to video record the whole *setup* or changeover process. In this study, we will refer to the preliminary stage as *Identification Stage.*

In a *setup* process, internal work refers to those activities that must be performed when the machines are stopped, whereas external work includes all those operations that can be performed while the machines are running. At stage 1 of SMED implementation, both internal and external *setup* activities must be clearly distinguished and then separated. This stage guarantees a reduction in *setup* time from 30% to 50% [12]. In this research, we will name stage 1 of SMED implementation the *Separation Stage*.

The second SMED implementation stage, known as the *Transformation Stage*, involves converting as much internal work to external work as possible. In other words, the goal is to perform the greatest amount of work while machines are running. At this stage, Shingo [12] suggests reexamining operations to find whether any steps have been wrongly assumed to be internal.

Finally, at the third stage, all aspects of the *setup* operation must be streamlined and standardized [12] to establish them as the new sequence to be followed. Eventually, all elements ought to be reviewed with an eye toward continuous improvement. In this research, we will refer to stage 3 of SMED implementation as the *Improvement Stage*.

2.3. Hypotheses Development. As mentioned earlier, SMED implementation comprises four conceptual stages. Since the objective of this research is to identify the relationships among these stages, in the following paragraphs we formulate and justify a series of hypotheses in order to study such relationships.

The only means to improve a setup/changeover process is to have enough statistical data of it, because a statistical analysis enables identifying the current status of the problem [19]. In this sense, statistical information may include data on the performed *setup* activities, including order of execution, time needed for making the tool changes, trends, and possible deviations from the process sequence [20]. Knowing this information simplifies decision-making when new methods are to be implemented, since companies become fully aware of the gaps that must be addressed. Other important sources of information are video recordings and the broad range of video recording equipment that is nowadays available allows for easy replay of scenes and frames, which helps companies meticulously analyze and document each SMED activity to detect and eliminate unnecessary work [9].

Once all SMED activities are identified and measured, organizations can move to the identification part to distinguish and separate work that can be performed while the machines are running from work that must be executed when the machines are stopped. Both internal and external work should be identified using a process diagram; otherwise it may be complicated to effectively separate it, and companies would have to stop the machines to ensure the safety of its plant when performing any setup/changeover [21]. To demonstrate that the *Identification Stage* affect the *Separation Stage*, the first working hypothesis is proposed as follows.

H_1. Activities performed at the *Identification Stage* of SMED implementation have a positive direct effect on activities performed at the *Separation Stage*.

Since one of the SMED objectives is to significantly reduce machine stoppage, some setup operations must be executed while it is running, always complying with the corresponding safety norms. After classifying all setup activities at the *Separation Stage*, operators must revise them to be sure the machine can actually be stopped [22]. It is advised to have all necessary equipment and tools at hand to perform the setup but also to remove those instruments that will not be required. Sometimes having too many objects at the workstation can cause accidents [23, 24]. Similarly, companies should use visual signs to signpost every movement required in each setup operation, although this is only possible if internal and external work are appropriately separated. To study the relationship between the *Identification Stage* and the *Transformation Stage* of SMED implementation, the second working hypothesis is proposed as follows.

H_2. Activities performed at the *Identification Stage* of SMED implementation have a positive direct effect on activities performed at the *Transformation Stage*.

Any process improvement methodology using lean techniques such as SMED must take pertinent measurements of the production process [24], since such measurements would allow companies to design an appropriate plan for continuous improvement. For this reason, experts argue that SMED activities to be executed must be measurable and expressed in appropriate units, so that all operators can understand them [25]. In addition, since such operators know best the production process, including changeovers, setups, risks, and opportunity areas, companies should constantly interview them to make sure the adopted measurement methods are appropriate. Also, new improvement proposals must be tape recorded to visualize performed changes [26]. This discussion allows us to assume that there is a significant relationship between setup work analyzed before and after the improvement process. We thus propose the third working hypothesis as follows.

H_3. Activities performed at the *Identification Stage* of SMED implementation have a positive direct effect on activities performed at the *Improvement Stage*.

At the *Separation Stage,* it is important to effectively categorize internal and external setup [27]; otherwise, if an activity is incorrectly classified, companies may be losing valuable time that can actually be productive for the machine [26]. The *Separation Stage* is also key to successful SMED implementation because, if properly conducted, it becomes easier and faster to move toward the *Transformation Stage*, at which companies must convert as much internal *setup* to external as possible [24]. Therefore, to study and test the relationship between the *Separation Stage* and the *Transformation Stage* during SMED implementation, the fourth working hypothesis is proposed.

H_4. Activities performed at the *Separation Stage* during SMED implementation have a positive direct effect on activities performed at the *Transformation Stage*.

Experts argue that if the *Separation Stage* is poorly executed, many opportunity areas will have to be addressed at the *Improvement Stage* [23, 28], yet SMED is a constant

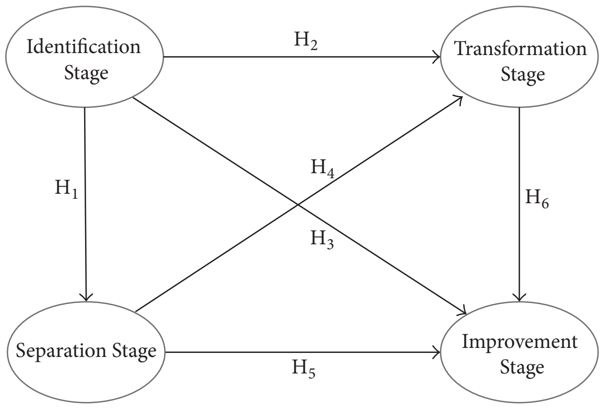

Figure 1: Initial model.

time-improvement seeker, which means that there are always opportunities for minimizing *setup*/changeover times and maximizing machine utilization. However, the *Separation Stage* should never be underestimated and must always be executed in the best possible way from the beginning, even though improvement opportunities may arise later [29]. Considering thus the importance of the first stage of SMED implementation for the correct execution of the third stage, the fifth working hypothesis is proposed.

H_5. Activities performed at the *Separation Stage* of SMED implementation have a positive direct effect on activities performed at the *Improvement Stage.*

As mentioned earlier, the *Transformation Stage* involves revising and reevaluating all the *setup* work previously classified to convert as many internal activities to external as possible. Thus, if any activity or operation is incorrectly classified at the *Separation Stage*, the *Transformation Stage* may be time-consuming [9, 23], since there will be more activities to convert than expected. Undoubtedly, appropriate classification and transformation of activities are the key to a successful SMED program [25]. For this reason, the final working hypothesis of our study reads as follows.

H_6. Activities performed at the *Transformation Stage* have a positive direct effect on activities performed at the *Improvement Stage.*

Figure 1 graphically presents the six working hypotheses integrated in a structural equations model.

3. Methodology

In this research, the following stages were followed to test, validate, and measure the relationships among the four conceptual stages of SMED stated as hypotheses.

3.1. SMED Activities Identification and Survey Design. To identify critical SMED activities, a literature review on SMED implementation is conducted in databases such as ScienceDirect, Springer, and IEEE, among others. Thirteen items in total for the four conceptual stages were identified and used to design a questionnaire and appears in Table 1. The questionnaire was administered to maquiladoras in Ciudad Juárez, namely, to maintenance staff and operators responsible for performing changeovers/setups. The survey was composed of two sections; the first one aimed to gather sociodemographic data, whereas the second section analyzed the four conceptual stages of SMED.

3.2. Survey Administration. To collect data, the survey was administered to Mexican maquiladoras located in Ciudad Juárez, mainly to workers performing changeovers/and setups in companies. The assessment for every item was in a Likert scale [30], because it is a popular method used for studying different aspects of the manufacturing industry, as in risks management in lean manufacturing implementation [31], the incremental contribution of lean management accounting practices [32], and the effects of manufacturing technologies and lean practices on manufacturing operational performance [33]. In this research, we relied on a five-point Likert scale to assess the importance of SMED activities. The lowest scale value (1) indicated that a SMED activity was never performed, whereas the highest value (5) implied that a SMED activity was always performed.

3.3. Data Capture and Screening. Gathered data were captured in a database on statistical software SPSS 21®. Following the data capture, we conducted a screening process to detect both missing values and outliers. Missing values occur when questions were not responded during the survey administration, and on the other hand, outliers reflect that a participant assesses an item with a value different to the used scale. To screen data in each questionnaire, the standard deviation of data was estimated [34] and discarded those surveys that showed a standard deviation below 0.5 [35] and box-plots help to identify outlier.

3.4. Survey Validation. To validate the survey items, seven indices were computed: *R*-Squared, Adjusted *R*-Squared, *Q*-Squared, Cronbach's alpha, Average Variance Extracted (AVE), Average Block Variance Inflation Factor (VIF), and Average Full collinearity VIF (AFVIF). On one hand, *R*-Squared and Adjusted *R*-Squared indices were used to measure parametric predictive validity of data [36], whereas *Q*-Squared is a measure of nonparametric predictive validity [37] whose values should be similar to *R*-Squared. On the other hand, we computed the Cronbach's alpha as a coefficient of reliability, only accepting values above 0.7.

We also computed AVE as a measure of discriminant validity, only accepting values equal to or higher than 0.5 [38]. Similarly, since VIF and AFVIF indices quantify multicollinearity [39], we looked for values below 3.3 to discard any collinearity problems [38].

3.5. Structural Equations Model. We employed the Structural Equations Modelling (SEM) technique to test hypotheses depicted in Figure 1 and using WarpPLS 5.0® software using factor-based partial least squares (PLS) because it combine precision of covariance SEM-based algorithms under common factor model assumptions with the characteristics of traditional PLS algorithms [38]. Then, we computed six

Table 1: SMED activities at its conceptual stages.

SMED stages	Activity	Description
Identification Stage	S0 02	Is a statistical analysis performed to know time variability of the process?
	S0 03	Is there a statistical analysis to know the average process?
	S0 04	Is there a detailed analysis of the possible causes of time variability in the process?
	S0 05	Have operators been interviewed about processes and the machines they operate?
	S0 06	Are operators' activities being measured with a chronometer?
Separation Stage	S1 01	List the main sequential setup operations to identify internal activities.
	S1 02	Detect basic problems that are part of the work routine.
	S1 03	Is the exchange of tools, parts, and supplies performed with the machine on?
Transformation Stage	S2 01	Is the previous work completed before starting the changeover?
	S2 02	Are visual marks used instead of making trial and error adjustments to calibrations?
	S2 03	Have steps for searching tools, raw materials, and products been eliminated?
	S2 04	Have activities been reexamined to make sure none of them was wrongly assumed to be internal?
Improvement Stage	S3 01	Have key setup activities been recorded to improve process time?
	S3 02	Have operators been trained to maintain improvement in processes?

model fit and quality indices proposed by Kock [38]: Average Path Coefficient (APC), Average R-Squared (ARS), Average Adjusted R-Squared (AARS), Average Variance Inflation Factor (AVIF), Average full Collinearity VIF (AFVIF), and the Tenenhaus Goodness of Fit (GoF), which is an indicator of good model fit to data [40]. For APC and ARS, we expected P values equal to or lower than 0.05 to test average statistical significance of relationships between latent variables at a 95% confidence level. On the other hand, preferred values for AVIF and AFVIF must be below 3.3.

Finally, to validate the model, we estimated and measured three types of effects between latent variables: direct, indirect, and total effects. For each effect, we tested the null hypothesis: H_0: $\beta = 0$ against the alternative hypothesis: H_1: $\beta \neq 0$ at a 95% confidence level. Direct effects appear in Figure 1 as arrows directly connecting two latent variables. In a causal diagram, the arrowhead defines the direction of the causal relationship; in other words, an arrow leading out of latent variable A into latent variable B indicates that the former variable has an effect on the latter, which is also known as the endogenous variable [38]. As regards the other two types of effects, indirect effects occur between two latent variables through mediator variables, whereas total effects are the sum of direct and indirect effects.

4. Results

4.1. Sample Description. After three months of administrating the questionnaire to different maquiladora in Ciudad Juárez, 250 valid questionnaires were collected. Figure 2 introduces a graph reporting the number of maquiladora employees surveyed per industrial subsector. As can be observed, the automobile industry led the research with 104 collected surveys, followed by the machining industry (45 collected surveys) and others (43 surveys). Note that five questionnaires did not report this information. Here it is important to say that 77% of responders were male and only 23% were female. Such results suggest that more male than female employees work in the maintenance departments of Mexican maquiladoras.

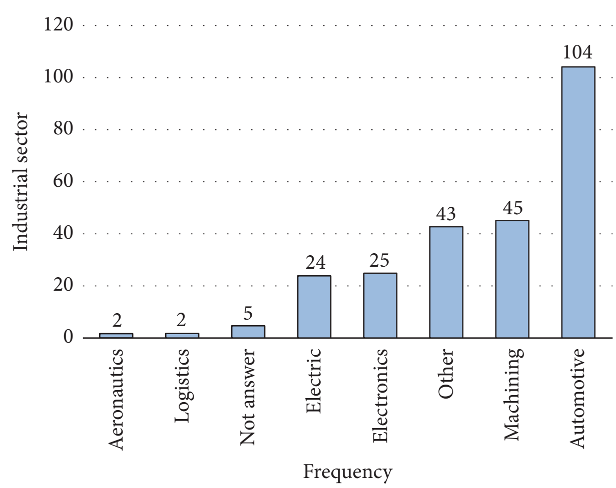

Figure 2: Surveyed industrial subsectors.

Table 2 shows the relationship between surveyed work positions and subsectors, and such information was reported in only 237 of the 250 collected surveys. Note that the automotive industry stood up as the most interviewed subsector with 101 collected questionnaires. As regards job positions, results from the analysis show technicians as the leading job position (99 respondents representing 40.5%), followed by operators (66 collected surveys). The remainder of the sample included engineers, supervisors, and mangers, providing 45, 25, and 5 surveys, respectively.

4.2. Survey Statistical Validation. As mentioned in the methodology section, we computed seven indices to validate latent variables. R-Squared, Adjusted-R-Squared, and Q-Squared indices indicated that variables had enough predictive validity from both parametric and nonparametric

Table 2: Contribution of work position and industrial subsector.

Job position	Industrial sector							
	Machining	Electrical	Automotive	Aeronautics	Electronics	Logistics	Other	Total
Manager	0	3	1	0	0	0	1	5
Engineer	2	7	27	0	3	1	5	45
Supervisor	4	3	13	0	2	0	3	25
Technician	22	4	40	0	15	1	14	96
Operator	17	6	20	2	4	0	17	66
Total	45	23	101	2	24	2	40	237

Table 3: Survey validation.

Index	Identification Stage	Separation Stage	Transformation Stage	Improvement Stage
R-Squared		0.443	0.390	0.366
Adj. *R*-Squared		0.440	0.385	0.358
Composite Reliability	0.885	0.911	0.855	0.823
Cronbach's alpha	0.837	0.851	0.774	0.770
Avg. Var. Extract. (AVE)	0.609	0.774	0.597	0.699
Full Collin. VIF	2.012	2.108	1.701	1.566
Q-Squared		0.444	0.392	0.368

Table 4: Model fit and quality indices.

Index	Value
Average Path Coefficient (APC)	0.343, $P < 0.001$
Average *R*-Squared (ARS)	0.400, $P < 0.001$
Average Adjusted *R*-Squared (AARS)	0.395, $P < 0.001$
Average Block VIF (AVIF): acceptable if ≤ 5, ideally ≤ 3.3	1.819
Average Full Collinearity VIF (AFVIF): acceptable if ≤ 5, ideally ≤ 3.3	1.847
Tenenhaus GoF (GoF): small ≥ 0.1, medium ≥ 0.25, large ≥ 0.36	0.517

perspectives. Likewise, since the Cronbach's alpha reported values above 0.7 in all cases, we concluded that all latent variables possessed enough internal validity. Also, AVE values, all above 0.5, validated convergent validity, whereas VIF values, all below 3.3, discarded collinearity problems within them. These indices and their values are shown in Table 3.

4.3. Structural Equations Model. Table 4 lists the six model fit indices computed to validate the model (see methodology section). Since P values of APC, ARS, and AARS were below 0.05, we concluded at a 95% confidence level that the model had enough predictive validity. Similarly, AVIF and AFVIF values. both below 3.3, discarded collinearity problems among latent variables, whereas the Tenenhaus GoF revealed a good model fit to data, since its value was above 0.517. In conclusion, all model fit and quality indices proved that the model could be analyzed in the full confidence and its interpretations would be valid.

4.3.1. Direct Effects. Direct effects appear illustrated in Figure 3 using arrows directly connecting two latent variables and represented as hypotheses. Every direct effect was associated with a beta (β) value and a P value; the former represented the dependency, expressed in standard deviations, between the two involved latent variables. For instance, we found that latent variable *Identification Stage* had a positive direct effect on latent variable *Separation Stage*, where $\beta = 0.67$ and $P < 0.01$. This means that when *Identification Stage* increases its standard deviation by one unit, the standard deviation of *Separation Stage* increases by 0.67 units; moreover, this relationship was statistically significant at a 95% confidence level, since its P value was lower than 0.05, even lower than 0.01. All direct effects between latent variables depicted in Figure 3 are similarly interpreted.

Every dependent latent variable was also related to an *R*-Squared value (R^2) that specified its amount of variance explained by independent latent variables. In the case of latent variable *Separation Stage,* its variability was explained 44.3% by *Identification Stage*, since $R^2 = 0.443$. However, sometimes more than one independent variable explain variability in a dependent variable. In this sense, the model's evaluation revealed that *Improvement Stage* was explained in 36.6% by the remaining three independent latent variables: *Identification Stage* (9.9%), *Separation Stage* (14.1%), and *Transformation Stage* (12.6), since $R^2 = 0.366$. Table 5 introduces all R^2 values found in the model. The portion

Table 5: Effect sizes of direct effects.

	Identification Stage	Separation Stage	Transformation Stage	R-Squared
Separation Stage	ES = 0.443 ($P < 0.01$)			0.443
Transformation Stage	ES = 0.309 ($P < 0.01$)	ES = 0.222 ($P < 0.01$)		0.390
Improvement Stage	ES = 0.258 ($P < 0.01$)	ES = 0.191 ($P < 0.01$)	ES = 0.126 ($P < 0.01$)	0.366

Table 6: Hypotheses validation.

Hypotheses	Independent variable	Dependent variable	β	P value	Conclusion
H_1	Identification stage	Separation stage	0.665	$P < 0.001$	Accept
H_2	Identification stage	Transformation stage	0.302	$P < 0.001$	Accept
H_3	Separation stage	Transformation stage	0.382	$P < 0.001$	Accept
H_4	Identification stage	Improvement stage	0.196	$P < 0.001$	Accept
H_5	Separation stage	Improvement stage	0.263	$P < 0.001$	Accept
H_6	Transformation stage	Improvement stage	0.249	$P < 0.001$	Accept

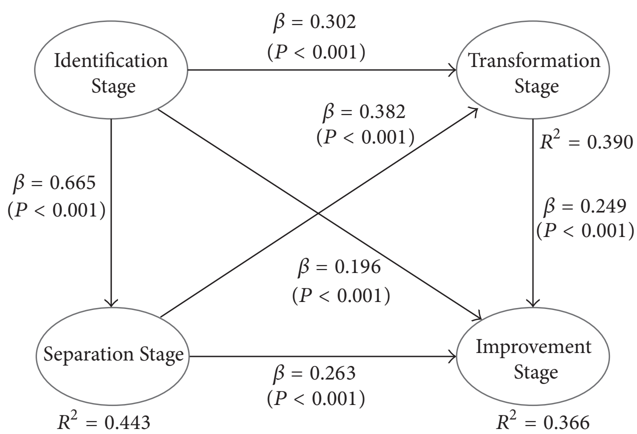

Figure 3: Final model.

of R^2 value explained by an independent latent variable in a dependent latent variable is known as effect size and is rounded up to the third significant decimal.

Since all the P values associated to β values were lower than 0.05, we computed the following standardized equations for relationships between latent variables:

$$\begin{aligned} &\text{Separation Stage} \\ &\quad = 0.665 \text{ Identification Stage} + \text{Error} \\ &\text{Transformation Stage} \\ &\quad = 0.302 \text{ Identification Stage} \\ &\qquad + 0.382 \text{ Separation Stage} + \text{Error} \\ &\text{Improvement Stage} \\ &\quad = 0.196 \text{ Identification Stage} \\ &\qquad + 0.263 \text{ Separation Stage} \\ &\qquad + 0.249 \text{ Transformation Stage} + \text{Error}. \end{aligned} \tag{1}$$

For hypotheses proposed in Figure 1 and tested in Figure 3, the following conclusions can be stated based on obtained β and P values shown in Table 6. For each hypothesis, the independent latent variable, the dependent latent variable, the β value, the P value associated, and the conclusion appear. The β value indicates that when the independent variable increases by one unit its standard deviation, the dependent variable increases that value and the P value indicates that all relationships are statistically significant; therefore, all hypotheses are accepted.

4.3.2. Indirect Effects. There were three indirect effects between latent variables through one or more mediator variables. The obtained P values proved that all indirect effects were statistically significant at a 95% confidence level. In that sense, it was found that activities performed at *Identification Stage* have the highest indirect effect on activities performed at *Improvement Stage*, since the indirect effect showed a higher value than its direct effect (0.314 versus 0.20) which is given through mediator variables *Separation Stage* and *Transformation Stage*. As for the effect size, it can be concluded that activities conducted at *Identification Stage* explained up to 15.9% of the variability of activities performed at *Improvement Stage*, since ES = 0.159.

In addition, the effect between *Identification Stage* and *Transformation Stage* given through *Separation Stage* whose value P is less than 0.001 indicating that the effect is significant with an effect size of 0.141 means that the *Identification Stage* variable explains 14.1% of the *Transformation Stage* variable. Finally, the effect between Separation Stage and Improvement Stage through the mediator variable called Transformation Stage shows a P value equal to 0.016. Thus, it can be concluded that the effect is significant and effect size is 0.051, indicating that the variable defined as Separation Stage explains 5.1% of the variable called Improvement Stage.

4.3.3. Total Effects. Total effects between two latent variables are the sum of their direct and indirect effects. Table 7 presents the total effects found in the evaluated model. Three

Table 7: Total effects.

	Identification Stage	Separation Stage	Transformation Stage
Separation Stage	0.665 ($P < 0.01$) ES = 0.443		
Transformation Stage	0.556 ($P < 0.01$) ES = 309	0.382 ($P < 0.01$) ES = 0.222	
Improvement Stage	0.510 ($P < 0.01$) ES = 0.258	0.358 ($P < 0.01$) ES = 0.191	0.249 ($P < 0.01$) ES = 0.126

total effects equaled direct effects, since in such relationships no indirect effects were found. Likewise, all P values were low enough to validate total effects at a 95% confidence level. As for the magnitude of effects, the largest total effect reported concerned latent variables *Identification Stage* and *Separation Stage*.

In the relationship between activities performed at the *Identification Stage* and those performed at the *Transformation Stage*, indirect effects represented 45.68% of total effects, although these effects were a bit lower than the direct effect (0.254 versus 0.302). Similarly, between activities performed at the *Identification Stage* and those performed at the *Improvement Stage*, total effects equaled 0.510 units and 0.196 came from the direct effect and 0.314 from the indirect effects. In this case, the latter were significantly higher than the former, representing 61.56% of the total effects. Similar interpretations were formulated for the remaining relationships.

5. Conclusions and Industrial Implications

In this research, we proposed six hypotheses to relate the four conceptual stages of SMED. By means of a structural equations model we demonstrated that all these relationships were statistically significant. Such findings allow us to discuss the following conclusions and industrial implications:

(1) We found the highest total effect in the relationship between the *Identification Stage* and the *Separation Stage* and these findings imply the following:

  (a) Prior to SMED implementation, companies must be fully aware of the current situation of setups and changeovers times required, since this would allow them to determine the current problem status. Information can be obtained measuring time and operations' movements, video recording the setup/changeover operations, and establishing a sequence for such operations as mentioned by Adanna and Shantharam [41].

  (b) All tools necessary to perform the setup/changeover must be at hand before the machines are stopped; otherwise companies may compromise machine availability and the production flow. A similar recommendation is given by Ferradás and Salonitis [9]

(2) In the relationship between *Identification Stage* and *Improvement Stage*, the indirect effects were visibly higher than the direct effect and that findings demonstrate that activities conducted at other stages are important mediator variables for a successful SMED implementation planning. These findings are in concordance with Choo et al. [19], because improving a setup/changeover process is important to have enough statistical data of it.

  In addition, the results show that to make a successful setup the video recording of the activities of SMED to detect those that are not adding value is necessary. As mentioned in Ferradás and Salonitis [9], video recordings allow for easy playback of scenes and frames, which helps companies to meticulously analyze and document each SMED activity to detect and eliminate unnecessary work.

(3) The relationship between *Identification Stage* and *Transformation Stage* showed the highest indirect effect, which demonstrates that making the appropriate classification of internal and external *setup* prevents from wasting time and increasing costs, as mentioned in Rodríguez-Méndez et al. [21].

(4) The most crucial stage in SMED implementation is the *Identification Stage*, which explains 44.3% of the variability in *Separation Stage*, the highest R^2 value found (see Figure 3), and this mean that if activities are not correctly identified, they will not be able to separate in an appropriate way and consequently cannot minimize the setup. This statistical finding is similar to reports from Rodríguez-Méndez et al. [21].

(5) Once SMED has been implemented, maquiladora companies need to monitor the setup/changeover once more, including timing and video recording, to identify the current status of the setup/changeover and detect potential improvement areas, thereby continuing with the continuous improvement cycle, as mentioned in Azizi and Manoharan [26].

(6) New machines must replace old ones as soon as their lifecycle ends. In this sense, some major decision criteria for evaluating and selecting machinery include time required for performing setups/changeovers and maintenance needs, since the processing times can vary due to the aging or deterioration of the machines [42]. In production, machines may be available from preventive maintenance, periodic repairs, or breakdowns. Maintenance activity is one of the best equipment operations management to enhance machine efficiency and improve product quality, as mentioned by Yang [43].

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors acknowledge the Mexican National Council for Science and Technology (CONACyT) for its support for this research.

References

[1] R. Villanueva-Ponce, J. L. Garcia-Alcaraz, G. Cortes-Robles, J. Romero-Gonzalez, E. Jiménez-Macías, and J. Blanco-Fernández, "Impact of suppliers' green attributes in corporate image and financial profit: case maquiladora industry," *International Journal of Advanced Manufacturing Technology*, vol. 80, no. 5-8, pp. 1277–1296, 2015.

[2] D. Shad and H. Soheil, "Enabling quality management systems in the maquiladoras: an empirical analysis," *International Journal of Quality & Reliability Management*, vol. 27, no. 9, pp. 981–1001, 2010.

[3] J. Hadjimarcou, L. E. Brouthers, J. P. McNicol, and D. E. Michie, "Maquiladoras in the 21st century: Six strategies for success," *Business Horizons*, vol. 56, no. 2, pp. 207–217, 2013.

[4] S. Dowlatshahi, "The role of industrial maintenance in the maquiladora industry: An empirical analysis," *International Journal of Production Economics*, vol. 114, no. 1, pp. 298–307, 2008.

[5] W. E. Forum, *The Global Competitiveness Report 2006–2007*, Macmillan, Geneva, Switzerland, 2006.

[6] A. H. Alad and V. A. Deshpande, "A review of various tools and techniques for lead time reduction," *International Journal of Engineering Development and Research*, vol. 2, no. 1, p. 6, 2014.

[7] R. M. Sousa, R. M. Lima, J. D. Carvalho, and A. C. Alves, "An industrial application of resource constrained scheduling for quick changeover," in *Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management, IEEM 2009*, pp. 189–193, chn, December 2009.

[8] S. Palanisamy and S. Siddiqui, "Changeover time reduction and productivity improvement by integrating conventional smed method with implementation of mes for better production planning and control," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 2, p. 12, 2013.

[9] P. G. Ferradás and K. Salonitis, "Improving changeover time: A tailored SMED approach for welding cells," in *Proceedings of the 46th CIRP Conference on Manufacturing Systems, CIRP CMS 2013*, pp. 598–603, Setubal, Portugal, May 2013.

[10] R. Assaf and T. Haddad, "Performance Improvement Using the Single Minute Exchange of Die (SMED) Methodology in an Aluminum Profiles Extrusion Production System," in *Proceedings of the 1st International Conference on Industrial, Systems and Manufacturing Engineering (ISME'14)*, CRC Press, Amman, Jordan, 2014.

[11] M. A. Musa, A. M. Ibrahim, S. Ravi, Z. F. Z. Abidin, and W. A. Wan Mat, "A case study and analysis of setup reduction for stamping dies—SMED approach," *Global Engineers & Technology Review*, vol. 4, no. 1, pp. 1–9, 2014.

[12] S. Shingo, "A Revolution In," in *Manufacturing The SMED System*, Productivity Press, 1985.

[13] M. S. Desai and R. M. Warkhedkar, "Productivity enhancement by reducing adjustment time and setup change," *International Journal of Mechanical & Industrial Engineering*, vol. 1, no. 1, p. 6, 2011.

[14] A. Teran-Somohano and A. E. Smith, "A setup reduction methodology from lean manufacturing for development of meta-heuristic algorithms," in *Proceedings of the 2013 IEEE Congress on Evolutionary Computation, CEC 2013*, pp. 3132–3139, Cancun, Mexico, June 2013.

[15] D. Ribeiro, "An Application of the SMED Methodology in an Electric Power Controls Company," in *Proceedings of International Conference On Innovations, Recent Trends And Challenges In Mechatronics*, p. 3, 2011.

[16] P. K. Bandyopadhyay, S. Naik, and K. Ganguly, "Reduction of Setup Time through SMED Approach:," *International Journal of Applied Management Sciences and Engineering*, vol. 2, no. 2, pp. 20–32, 2015.

[17] R. M. Yashwant and K. H. Inamdar, "Changeover time redution using SMED technique of lean manufacturing," *International Journal of Engineering Research and Applications*, vol. 2, no. 3, pp. 2441–2451, 2012.

[18] J. Berk, *Cost Reduction and Optimization for Manufacturing and Industrial Companies*, John Wiley & Sons, Inc., Hoboken, NJ, USA, 2010.

[19] A. S. Choo, R. Nag, and Y. Xia, "The role of executive problem solving in knowledge accumulation and manufacturing improvements," *Journal of Operations Management*, vol. 36, pp. 63–74, 2015.

[20] M. A. Almomani, M. Aladeemy, A. Abdelhadi, and A. Mumani, "A proposed approach for setup time reduction through integrating conventional SMED method with multiple criteria decision-making techniques," *Computers and Industrial Engineering*, vol. 66, no. 2, pp. 461–469, 2013.

[21] R. Rodríguez-Méndez, D. Sánchez-Partida, J. L. Martínez-Flores, and E. Arvizu-Barrón, "A case study: SMED & JIT methodologies to develop continuous flow of stamped parts into AC disconnect assembly line in Schneider Electric Tlaxcala Plant.," *IFAC-PapersOnLine*, vol. 28, no. 3, pp. 1399–1404, 2015.

[22] R. Sundar, A. N. Balaji, and R. M. Satheesh Kumar, "A review on lean manufacturing implementation techniques," in *Proceedings of the 12th Global Congress on Manufacturing and Management, GCMM 2014*, pp. 1875–1885, Vellore, India, December 2014.

[23] B. Strickland, "Quick Changeover for Operators: The SMED System," *Journal of Manufacturing Systems*, vol. 16, no. 3, pp. 233-234, 1997.

[24] J. Filla, "The Single Minute Exchange of Die Methodology in a High-Mix Processing Line," *Journal of Competitiveness*, vol. 8, no. 2, pp. 59–69, 2016.

[25] I. W. Adanna and A. Shantharam, "Improvement of Setup Time and Production Output with the use of Single Minute Exchange of Die Principles (SMED)," *International Journal of Engineering Research*, vol. 2, no. 4, pp. 274–277, 2013.

[26] A. Azizi and T. a. Manoharan, "Designing a Future Value Stream Mapping to Reduce Lead Time Using SMED-A Case Study," *Procedia Manufacturing*, vol. 2, pp. 153–158, 2015.

[27] R. I. McIntosh, S. J. Culley, A. R. Mileham, and G. W. Owen, "A critical evaluation of Shingo's 'SMED' (Single Minute Exchange of Die) methodology," *International Journal of Production Research*, vol. 38, no. 11, pp. 2377–2395, 2000.

[28] M. Kemal Karasu, M. Cakmakci, M. B. Cakiroglu, E. Ayva, and N. Demirel-Ortabas, "Improvement of changeover times

via Taguchi empowered SMED/case study on injection molding production," *Measurement: Journal of the International Measurement Confederation*, vol. 47, no. 1, pp. 741–748, 2014.

[29] A. Simões and A. Tenera, "Improving setup time in a press line - Application of the SMED methodology," *IFAC Proceedings Volumes*, vol. 17, pp. 297–302, 2010.

[30] R. Likert, "A technique For Measurement Of Attitudes," *Archives of Psychology*, vol. 22, no. 140, p. 51, 1939.

[31] W. Widiasih, P. D. Karningsih, and U. Ciptomulyono, "Development of Integrated Model for Managing Risk in Lean Manufacturing Implementation: A Case Study in an Indonesian Manufacturing Company," *Procedia Manufacturing*, vol. 4, pp. 282–290, 2015.

[32] R. R. Fullerton, F. A. Kennedy, and S. K. Widener, "Lean manufacturing and firm performance: The incremental contribution of lean management accounting practices," *Journal of Operations Management*, vol. 32, no. 7-8, pp. 414–428, 2014.

[33] T. Khanchanapong, D. Prajogo, A. S. Sohal, B. K. Cooper, A. C. L. Yeung, and T. C. E. Cheng, "The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance," *International Journal of Production Economics*, vol. 153, pp. 191–203, 2014.

[34] C. Wang, J. Li, and P. Guo, "The normalized interval regression model with outlier detection and its real-world application to house pricing problems," *Fuzzy Sets and Systems. An International Journal in Information Science and Engineering*, vol. 274, pp. 109–123, 2015.

[35] J. L. García-Alcaraz and A. A. Maldonado-Macías, *Just-in-Time Elements and Benefits*, Springer, 2016.

[36] J. M. Wooldridge, "A note on computing r-squared and adjusted r-squared for trending and seasonal data," *Economics Letters*, vol. 36, no. 1, pp. 49–54, 1991.

[37] N. Kock, "Using warpPLS in e-collaboration studies: What if i have only one group and one condition?" *International Journal of e-Collaboration*, vol. 9, no. 3, pp. 1–12, 2013.

[38] N. Kock, "WarpPLS 5.0 User Manual," ScriptWarp Systems, Laredo, Tex, USA, 2015.

[39] G. Udo, K. Bagchi, and M. Maity, "Exploring Factors Affecting Digital Piracy Using the Norm Activation and UTAUT Models: The Role of National Culture," *Journal of Business Ethics*, vol. 135, no. 3, pp. 517–541, 2016.

[40] M. Tenenhaus, "PLS path modeling," *Computational Statistics Data Analysis*, vol. 48, no. 1, pp. 159–205, 2005.

[41] I. W. Adanna and A. Shantharam, "Improvement of Setup Time and Production Output with the use of Single Minute Exchange of Die Principles (SMED)," in *Proceedings of the International Journal of Engineering Research*, vol. 4, p. 274, 2013.

[42] Y. Zarook, J. Rezaeian, R. Tavakkoli-Moghaddam, I. Mahdavi, and N. Javadian, "Minimization of makespan for the single batch-processing machine scheduling problem with considering aging effect and multi-maintenance activities," *International Journal of Advanced Manufacturing Technology*, vol. 76, no. 9-12, pp. 1879–1892, 2014.

[43] D.-L. Yang, "Unrelated parallel-machine scheduling with aging effects and multi-maintenance activities," *Computers Operations Research*, vol. 39, no. 7, pp. 1458–1464, 2012.