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Assessing the impact of Lean manufacturing on the Social Sustainability through Structural Equation Modeling and System Dynamics

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Abstract

This study presents a comprehensive approach to evaluate the impact of various Lean Management tools, such as Kaizen, Total Productive Maintenance (TPM), Just-in-Time (JIT), and philosophies like Total Quality Management (TQM)on the social sustainability of manufacturing companies. Using a system dynamics model supported by structural equation analysis, we seek to measure these effects and determine the time required for companies to reach the desired level of implementation of these tools and the point at which they will achieve social sustainability. This innovative approach seeks to fill a gap in the research, as so far, no studies have been conducted that precisely measure the impact of Kaizen, TPM, JIT, and philosophies like TQM on social sustainability using structural equation modeling and system dynamics. This gap in the literature highlights the relevance of this study, which provides detailed results on the impact of Lean Management tools on social sustainability and addresses a significant gap in existing research. Data were collected from 411 surveys, primarily from companies in the automotive sector with more than 1,000 employees. The analysis used tools such as WarpPls 8.0® for structural equation analysis and STELLA ARCHITECT V3.0.1® for system dynamics. The results suggest that continuous improvement is fundamental to achieving social sustainability, serving as an enabler for tools such as TPM and JIT, which are integral to Lean Management, as well as philosophies like TQM. The projection indicates that achieving 100% implementation of these Lean Management tools will take approximately seven years while attaining 100% social sustainability is expected within 10.25 years. It's important to note that while Lean Management tools like TPM and JIT play a crucial role, TQM, as a separate philosophy, also contributes significantly to social sustainability. Although these timelines are ambitious and theoretical, they underscore the critical importance of Lean Management tools for social sustainability. Caution is advised, acknowledging the potential challenges of achieving such ambitious goals, which should be approached with realism.

Keywords: Social Sustainability, Lean ManagementTools, System Dynamics, Structural equation model.

1. Introduction

The maquiladora industry has played an essential role in the Mexican manufacturing sector and emerged to provide manufacturing products and employment opportunities for Mexicans. The Mexican government established regulations that allowed domestic and foreign companies to import materials and equipment and export temporarily finished products at preferential tariff rates [1].This industry represents a form of international operation that implies a flexible, agile and inexpensive mode of operation, along with the need to provide an efficient supply chain network and turn Mexico into an exporting country that attracts foreign investment to which many companies arrive.

These industries bring many industrial processes, state-of-the-art machinery, and production philosophies, includingLean Management(LM). LM is a comprehensive approach to eliminating waste and improving efficiency in various industries, such as manufacturing, healthcare, and construction[2]. It is an integrated socio-technical system that reduces or minimizes variability in supplier, customer, and internal processes. LM is widely perceived as a means

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to reduce waste without additional resources, making it an attractive strategy for industries seeking operational efficiency[3].

However, successful LM implementation requires a cultural change within the organization, focusing on continuous improvement and waste reduction[2]. LM reduces overproduction, defects, unnecessary transportation, excessive inventory, waiting, non-essential movement, rework, and excessive processing.

The maquiladora industry benefits from LM practices by improving efficiency, reducing waste, and increasing competitiveness [4]. In addition, it allows companies to organize production processes and provide goods and services with the quality characteristics the consumer requires in minimum time and at the lowest cost.For example, practices such as cycle time reduction, reduced setup times, tidiness and cleanliness 5S and the use of "error-proof" equipment help to create a regular and uniform flow, fewer defects and energy usage, which leads to reduce the environmental footprint and improve their environmental performance [5].

Most studies relating to LM focus on operational and financial aspects; however, there is a lack of studies focused on relating it to social sustainability (SOS) [6], as the latter is often overlooked in favor of environmental concerns and to mention that a company is sustainable, it must balance its environmental, economic and social performance [5]. This requires integrating social sustainability criteria and environmental and economic sustainability in organizational processes.

Studies have shown that LM and supply chain agility can positively impact SOS [7]or that LM practices are an antecedent of SOS by minimizing accidents and occupational hazards or that LM, SOS and green competitiveness of firms are associated with the adoption of environmentally friendly technology and innovation [8] These studies have been conducted in Brazil, Portugal, China and India. There are no known studies in Mexico in which similar analyses are conducted.

This research delves into an analysis of how the adoption of Total Quality Management (TQM), Total Productive Maintenance (TPM), Just in Time (JIT), and Kaizen practices impact the Social Sustainability (SOS) of Mexican Maquiladora Companies. The prominence of this industry underscores the significance of this investigation. According to the Maquiladora Association, AC (INDEX Juarez), in May 2023, Ciudad Juarez (Mexico) accommodated 337,107 employees within this sector, signifying 11.38% of the total national workforce.In addition, 322 Maquiladora companies are registered in the Manufacturing, Maquiladora and Export Services (For its acronym in SpanishIMMEX) program, representing6.24% of the national total[9]. In this sense, this industry is vital for the region since it generates many direct jobs.

In that sense, this study, using a system dynamics model supported by structural equation model analysis, seeks to measure the effects of tools such as Kaizen, TPM, JIT and philosophies like TQM and to determine the time required for companies to reach the desired level of implementation of these tools and the point at which they will achieve social sustainability. This innovative approach aims to fill a gap in research, as until now, no studies have been conducted that accurately measure the impact of Kaizen, TPM, TQM and JIT on social sustainability using structural equation modeling and system dynamics. This lack of research highlights the relevance of this study, which provides detailed results on the impact of Lean Management tools on social sustainability and addresses a significant gap in existing research.

After this introduction, section 2 reports a literature review related to LM tools and the SOS; likewise, the relationships established as hypotheses for the causal analysis are justified. Section 3 describes the methodology used to conduct this research; section 4 shows the results, and section 5 details the conclusions.

2. Literature Review and Hypothesis

2.1. Kaizen

Kaizen (KAI), a Japanese term meaning "change for the better" or "continuous improvement," is a philosophy deeply rooted in the principles of Total Quality Management (TQM) and Lean thinking[10].It emphasizes making small, incremental changes to processes and systems to improve efficiency and quality. Kaizen involves the active participation of all employees, from top management to workers, in identifying and implementing improvements in their daily work. This philosophy fosters a culture of continuous improvement to eliminate waste, reduce variation, and increase productivity at all organizational levels[11]. It is based on the principles of continuous improvement, respect for others and collaboration and involves making small incremental changes to improve efficiency and quality. It is often implemented through various tools and techniques, such as the 5S and Kanban.

Kaizen has been successfully applied in various sectors, such as manufacturing, healthcare, and public utilities , and has been shown to positively impact operational efficiency, employee satisfaction, lead times, and defect reduction, resulting in quality improvement[12]. In that sense, Kaizen is a valuable approach for organizations seeking sustainable success through improvement.

2.2. Total Quality Management (TQM)

Total quality management (TQM) is a systematic improvement of the quality approach to the whole company to improve quality, productivity, profitability and shareholders for business and customer satisfaction[13], and its goal is to continuously improve design processes and manufacturing plans applied to manufacturing lines. TQM means that all workers in each organization should be involved in improving product or service quality. TQM involves techniques such as statistical process control to ensure compliance with technical specifications[14]; however, it focuses on pre-manufacturing phases such as planning, design, and prototyping. In manufacturing, TQM can be implemented through practices such as Kaizen, which involves continuous improvement and employee involvement [15].

As a philosophy of continuous improvement, Kaizen has proven to have benefits in TQM because quality is one of the aspects to be improved in production lines, as it favors eliminating waste and reducing problems. In addition, Kaizen has been shown to increase profitability through product quality and sales growth[11]. Kaizen generally allows organizations to improve quality incrementally and is considered a philosophy focused on progressive change that increases profitability [16]. In that sense, the following hypothesis can be put forward:

H_1: Kaizen has a direct positive effect on TQM.

2.3. Total Productive Maintenance (TPM)

The ultimate goal of any maintenance regime is to maintain system functionality as much as possible with an optimal balance between downtime and maintenance cost, avoiding dangerous failures. Total Productive Maintenance (TPM) is a new maintenance strategy developed to meet new maintenance needs. TPM is an American style of productive maintenance that has been modified and improved to suit the Japanese industrial environment[17].TPM is a manufacturing initiative primarily formulated to enhance equipment efficiency throughout its lifespan through the active participation and motivation of the entire workforce and seeks to optimize the productivity of manufacturing equipment and is considered a Lean Management (LM) tool for improving performance and sustainability [18]. In conclusion, TPM focuses on maintaining and improving the integrity of production systems and quality through machines, equipment, and processes that add value to the product, avoiding breakdowns, delays, minor stoppages, and defects during the production process while providing a safe working environment and minor error [2, 19]. The eight pillars of TPM constitute a system for maximizing production efficiency in any industry and are described below.

- Autonomous Maintenance. Train equipment operators to perform essential equipment maintenance tasks.
- Planned Maintenance. Maintenance is scheduled using the historical failure rate of equipment.
- Quality Maintenance. Integrated quality in equipment to reduce defects.
- Continuous Improvement (Kaizen). Use of cross-functional teams for improvement activities
- Early Equipment Management. Design of new equipment learned from previous TPM activities.
- Training & Education. Closing the skills and knowledge disparity by providing training for all employees and minimize errors [20].
- Health. Safety & Environment. Establishing an optimal work environment free from accidents and injuries.
- TPM in the Office. Integration of principles into administrative functions within an organization.

According to last paragraphs, TPM influences the performance of manufacturing companies since it allows for improving equipment availability, which is done gradually. For example, when all the machines are in optimal conditions, cycle time and in-process inventory are reduced, and it is associated with skill levels for the use and handling of machines by employees and customer satisfaction [21].

Thus, implementing TPM improvement plans reduces scrap rates, inventory, costs, machine downtime, productivity, and on-time delivery of customer orders. In this regard, the following hypothesis can be put forward:

H_2: Kaizen has a direct and positive effect on TPM

However, applying TPM on production lines is necessary to generate quality products since properly calibrated machines generate less waste that goes to landfill or must be reprocessed[17]. Also, considering that quality is associated with deliveries on time and in the agreed quantity, if the machines are out of order, they require repair time, and this affects the product cycle time, which may affect delivery times to the customer, who, because of that failure, may consider the product as low quality.

Likewise, it is possible that with machines in poor condition, the OEE decreases due to their low availability, which affects the timely fulfillment of orders, again affecting a dimension of quality valued by the customer[2]. Thus, considering that TPM promotes TQM, the following hypothesis is proposed:

H_3. TPM has a direct and positive effect on TQM.

2.4. Just-in-time (JIT)

JIT is a production strategy to minimize inventory levels and reduce waste by producing and delivering products or services when needed, in the quantity they are needed and with the quality requested by the customer. As a result, JIT allows to reduce inventory costs[7], synchronize the flow of materials and information throughout the production process; moreover,it favors on-time deliveries according to contracts[22]. The application of Lean methods and tools, including JIT, has been shown to reduce lead times, activity duration and material waste, which has a positive impact on operational performance.

As a fundamental principle of LM, Kaizen involves minor improvements made by front-line workers, starting with material flow [23]. Implementing JIT and Kaizen simultaneously reduces lead time, processing time, work in process and labor requirements while increasing productivity. Kaizen has been shown to favor cost reduction, process improvement and time savings associated with the production flow, as it identifies activities that do not add value when mobilizing raw materials and finished products[10]. Thus, the following hypothesis can be put forward.

H_4: Kaizen has a direct and positive effect on JIT

Product quality is also reflected by on-time delivery performance, so companies that implement TQM must consequently implement JIT and meet that requirement. In addition, TQM emphasizes continuous improvement, customer focus, and employee involvement, which aligns with the principles of JIT [24].

Also, simultaneous implementation of TQM and JIT has proven to provide further agility to the productive processes, quickly facing disruptive risks in the supply chain, allowing many companies to achieve ISO 9000 certifications [25]. In that sense, the combination of TQM and JIT can improve performance, efficiency and customer satisfaction in organizations by making complete and on-time deliveries, so the following hypothesis is put forward:

H_5: JIT has a direct and positive effect on TQM

Machines with breakdowns due to lack of maintenance can prevent having on-time deliveries to production orders, which affects the company's reputation. Recall that TPM focuses on maximizing equipment effectiveness, reducing breakdowns, and improving overall efficiency[26];then, by implementing TPM, companies can improve their JIT operations by minimizing downtime, improving equipment reliability, and reducing the need for buffer stock.

Studies have shown that TPM and JIT work synergistically to improve operational performance and reduce costs; however, the best thing about TPM is that it helps to create a culture of continuous improvement and employee involvement, which is crucial for a successful JIT implementation. Thus, the integration of TPM and JIT reduces lead times and increases the economic productivity of companies[26] and optimize the batch size [3], which allows the following hypothesis to be put forward.

H_6: TPM has a direct and positive effect on JIT

2.5. Social Sustainability (SOS)

SOS refers to an organization's impact on the social systems in which it operates and is a dimension of sustainability that considers the well-being of people and communities. SOS involves promoting human capital and social capital in the communities an organization works with [27]. Thus, SOS in manufacturing refers to integrating socially responsible behaviors and practices within manufacturing processes to achieve sustainability and involves integrating factors such as worker health and safety, human rights, equity, and diversity into strategic plans [28].

By maximizing equipment efficiency and reducing breakdowns, TPM helps minimize the negative social impacts of maintenance, such as downtime, waste, and low throughput, contributing to the overall sustainability of production processes and reducing the social costs associated with inefficient maintenance practices. In addition, TPM fosters a culture of continuous improvement and employee involvement, which can lead to increased awareness of risks when operating machines, thus preventing accidents that affect the integrity of the machines[29].

Similarly, poorly calibrated machines generate products that must be reprocessed or sent to local landfills, representing a source of pollutants. In addition, the operator may feel exposed to possible physical injuries, decreasing their work commitment and motivation [30]. For this reason, the following hypothesis is proposed:

H_7: TPM has a direct and positive effect on SOS

However, SOS can have several sources, and JIT is one of them; for example, by enabling quick delivery of materials, information and other inputs needed for a project, reducing the need for excess inventory and minimizing waste makes operators feel that they are meeting goals, which fills them with pride. In addition, the implementation of JIT is accompanied by other Lean Management Tools (LMTs), such as TQM, which involve the integration of workers, making them feel part of the solution to the problems in the production lines [31].

Also, the involvement of workers in JIT implementation positively affects the implementation of other Lean Management Tools (LMTs) aligned with social sustainability goals. In addition, the integration of JIT and other LMTs has been shown to create a culture of continuous improvement, worker engagement and increased awareness of the problems associated with SOS [32], so the following hypothesis is proposed:

H_8: JIT has a direct and positive effect on SOS

Figure 1 illustrates the relationships between the hypothesized variables.

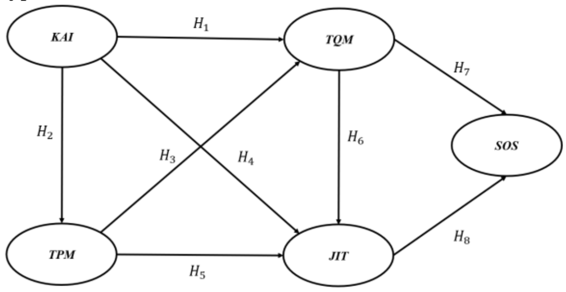

Figure. 1 Proposed Model

2.6. System Dynamics (SD)

SD refers to the study of the behavior and interactions of complex systems over time and involves analyzing how the different components of the system, such as variables, feedback loops and causal relationships, influence and interrelation By visualizing a system as a feedback process in a causal loop and using action and flow diagrams, SD can capture the dynamic behavior of a system [33].

SD is applied to various fields, such as physics, engineering, biology, economics, and social sciences, to understand and predict the behavior of complex systems because it considers the behavior of variables over time. Systems can exhibit transient responses during start-up or when subjected to external perturbations, and SD helps to understand and predict these responses. In addition, SD considers the interactions and interdependencies between the different components of a system, recognizing that changes in one of these can have cascading effects on the entire system.

The use of SD in manufacturing involves understanding the interactions and relationships between the various system components and processes and how they affect the overall dynamics of the system [34]. The use of SD in manufacturing involves understanding the interactions and relationships between the various components and processes of the system and how they affect its overall dynamics as these are complex and dynamic, with multiple variables influencing their performance, such as production processes, equipment, materials, human resources, and external factors such as market demand and supply chain dynamics.

The modeling and analysis provided by SD allow for predicting the behavior of systems under different conditions and scenarios [34, 35]. Thus, creating mathematical models representing the various components and processes within the system can simulate different scenarios, and the impact of changes in system performance can be evaluated [34]. The above helps optimize production processes by proposing the best configuration and parameters, identifying the scope of desired performance targets, maximizing productivity, minimizing costs or improving quality [35].

In manufacturing, SD is used in shop floor scheduling, as shop floors are characterized by uncertain factors and dynamic environments, making scheduling difficult. Thus, SD models and simulates material flow in flexible manufacturing systems, optimizes system architecture, and evaluates different processing scenarios to improve throughput and efficiency.

SD has been applied to simulate operations and identify optimal inventory policies to cope with dynamic supplier disruption risk in designing and optimizing manufacturing systems to model and analyze the interaction between customer behavior, business strategy, and economic viability [36]. In that sense, SD is a valuable approach in manufacturing that allows modeling, simulating and optimizing manufacturing systems.

3. Methodology

This work was carried out in two stages, as outlined below.

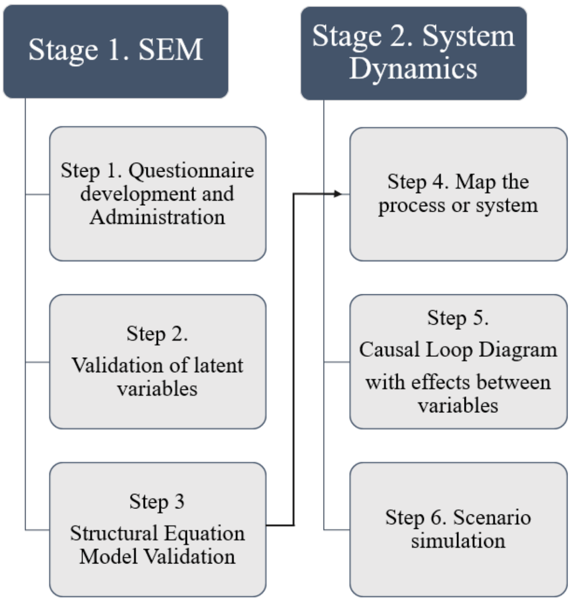

Figure 2. Methodology

3.1. Structural equation modeling

This stage describes the steps to validate the hypotheses proposed in Fig. 1.

3.1.1. Questionnaire Development and Administration

Information was collected from the maquiladora industry established in Ciudad Juarez (Mexico) through a questionnaire to validate the hypotheses proposed in Figure 1. The above was created through a literature review to identify the most critical activities in implementing each LMT and the sustainable benefits (social, economic, and environmental) obtained.

The initial questionnaire consisted of 3 sections: demographic data, LMTs and Benefits obtained. It was generated from the literature review, which was then validated by expert judgment with the help of academics and managers working in the Maquiladora industry. The questions were to be answered on a 5-point Likert scale, where 1 means strongly disagree, 2 means disagree, 3 means neutral, 4 means disagree, and 5 means strongly agree.

The sample was identified with the help of the association of maquiladoras AC. It was aimed at managers, engineers, technicians, supervisors and operators who have been involved in the implementation of LMTs. Contact was initiated with each participant by email, inviting them to participate. In cases where no response was received, a follow-up email was sent as a reminder. The case was considered inactive unless a response was obtained after the second email. The questionnaire was administered using the Google Forms platform between January 15 and April 15, 2022.

The final questionnaire contained 207 questions (activities) divided into 35 LMTs and 27 social, environmental and economic sustainability benefits. The LMTs included in this research are only JIT, Kaizen, TQM TPM and SOS. The final questionnaire used is found as supplementary material.

3.1.2. Debugging of information and Validation of latent variables

At the end of the questionnaire application period, the data were downloaded from the Google Forms platform in a .xls file exported to the SPSS 25® software for debugging. The standard deviation of each questionnaire was calculated to check the engagement of the participants, and if the standard deviation was less than 0.5, the questionnaire was eliminated. In addition, extreme values were identified by standardizing the item values, where values greater than 4 and less than -4 were replaced by the median[37].

Once the purification was completed, the latent variables were validated using the indexes proposed by Kock [37] (see Table 1). The first column shows the indexes, the second column shows the type of Validation, and the third column indicates the suggested cut-off value.

Table 1. Validation indexes

Indexes	Measurement	Suggested value
R^2	Predictive parametric Validation	≥ 0.20
Adjusted R^2		
Composite Reliability	Internal consistency	≥ 0.70
Cronbach's Alpha		
Average Variance Extracted (AVE)	Discriminant validity	≥ 0.50
CompleteCollinearity variance inflation factor (VIF)	Collinearity	≤ 3.30
Q^2	Predictive non-parametric validity	> 0.00 and similar to R^2

3.1.3. Validation of relationships between variables

The structural equation modeling (SEM) technique was used to validate the relationships between variables in Figure 1. SEM has been used to analyze the measurement and structural models of ISO 9001 certification[15]. The Partial Least Squares (PLS) approach was used to evaluate the model since it does not require large samples to provide reliable results, and the PLS-SEM combination is flexible. It allows the inclusion of multiple latent variables with different roles as dependent or independent variables.

The SEM was evaluated in WarpPLS 8.0® software, and before making the corresponding interpretations, the quality and fit indexes recommended byKock [37]are presented in Table 2. The objective of using SEM is to quantitatively obtain an independent variable's influences on a dependent variable and generate regression coefficients (Beta β) and the weights of the items that comprise them (*w*).

Table 2. Model Fit and Quality Index

Index	Measurement	Cut-off value
Average path coefficient (APC)	Predictive Validity	P < 0.05
Average R-squared (ARS)		
Average adjusted R-squared (AARS)		
Average block VIF (AVIF) = 1.550	Collinearity	acceptable if ≤ 5, ideally ≤ 3.3
Average full collinearity VIF (AFVIF)	Collinearity	
Tenenhaus Goodness of Fit (GoF)	Model fit	small ≥ 0.1, medium ≥ 0.25, large ≥ 0.36

3.2. System Dynamics

3.2.1. Causal Loop Diagram (CLD)

Once the SEM was analyzed and the values of the regression coefficients and item weights were obtained, the CLD was made, a visual representation of the system's causal relationships and feedback loops. In this case, the variables are connected by arrows that indicate the direction of causality between cause and effect [38]. The CLD represents the interdependencies between the variables, their interactions and feedback mechanisms. In this case, Figure 3 presents the interdependencies of the variables related to each LM tool.

KAI is the independent variable, and SOS is the dependent variable. TPM, TQM and JIT act as both dependent and independent variables. The CLDs include reinforcing loops representing positive feedback, where an increase in one variable leads to an increase in another. They also include equilibrium loops representing negative feedback, in which an increase in one variable leads to a decrease in another [39]. In Figure 3, only reinforcing loops represent the indicator weights for each latent variable (the blue arrows) and the influence of one latent variable on another (black arrows). These reinforcing loops can be observed since a "+" sign is added above the tip of each arrow as a positive flow. It is essential to mention that equilibrium loops were also added to the model(Figure 6).

However, to know the variables' feedback, a new SEM is generated in which the direction of the relationships is reversed; that is, the independent variable is SOS, and the dependent variable is KAI. The feedback model is illustrated in Figure 4, where the subscript r of the hypotheses means feedback.

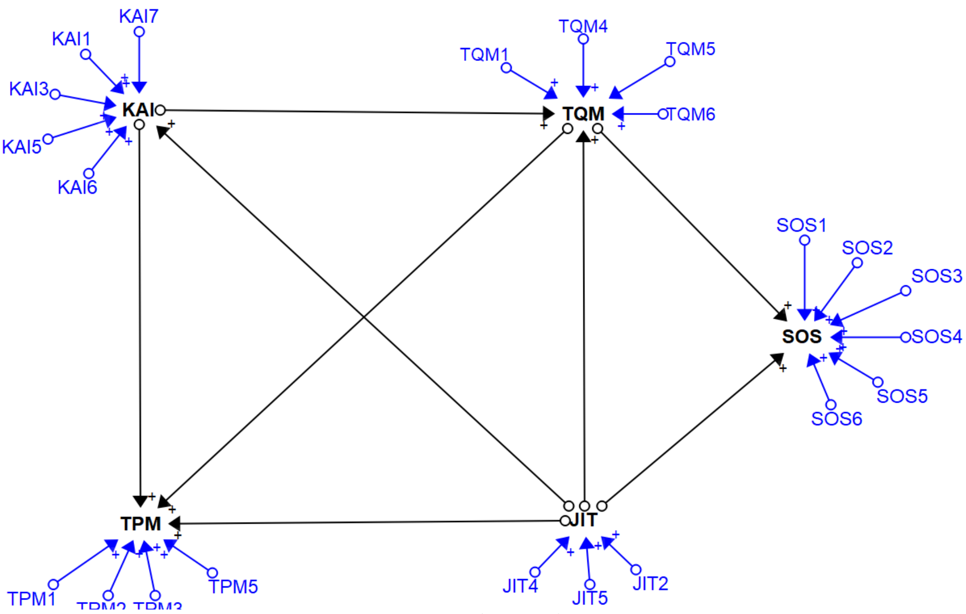

Figure 3. Causal Loop Diagram

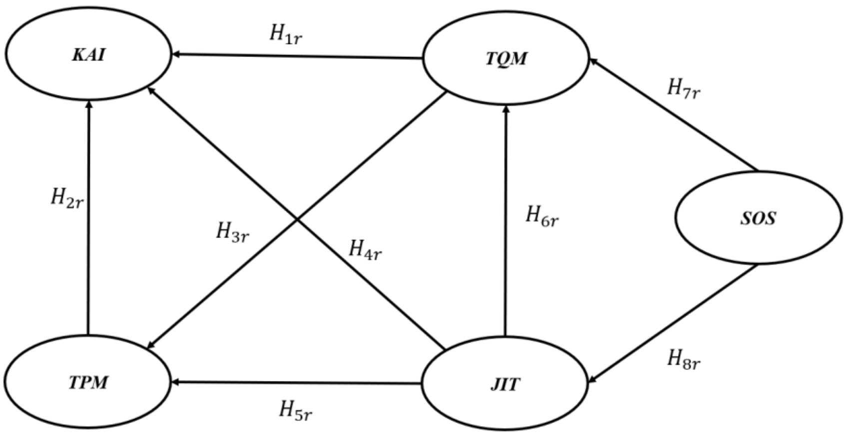

Figure 4. Feedback model

4. Results

4.1. Descriptive analysis of the sample

Table 3 shows the industrial sector and the job position of each participant, and the automotive sector was the one that participated the most. In addition, the job position that participated the most was that of engineer.

Table 4 shows the size of the company and the experience of each of the participants. Regarding the size of the companies, 60.5% have more than 1,000 workers, making them large companies. 24.48% have more than 5,000 workers and 11.6% have more than 10,000 workers. Regarding the work experience of the respondents, 79.8% have more than twoyears of experience, 46% have more than 5, and 21% have more than tenyears.

4.2. Validation of latent variables

Table 5 illustrates the values of the validation indices for the latent variables for the proposed model in Figure 1 and the feedback model in Figure 4. It was concluded that there is sufficient parametric and non-parametric, predictive and convergent validity and no collinearity problems. Finally, the Normal-JB normality test is reported, indicating that no variable has a normal distribution, which justifies the PLS-SEM approach.

Cronbach's alpha index was obtained iteratively, and not all items remained in the latent variable since eliminating some of them increased their value. In this case, the variables with the following items are analyzed: Kaizen (KAI1, KAI3, KAI5, KAI6, KAI7), JIT (JIT2, JIT3, JIT5), TQM (TEQM1, TQM4, TQM5, TQM6), TPM (TP1, TPM2, TPM3, TPM5) and SOS (SOS1, SOS2, SOS3, SOS4, SOS5, SOS6). For the meaning of each item, see Appendix 1 and the questionnaire in the repository.

4.3. Structural Equation Model Validation

The validated variables were integrated into the SEM to establish and validate causal relationships. Table 6 illustrates the efficiency indexes for the proposed model and the feedback model, showing the quality and fit indexes, which reflect predictive validity since the APC, ARS and AARS are statistically significant; in addition, there is no collinearity in the variables since the AVIF and AFVIF are less than 3.3, and the data fit the model adequately since the GoF are more significant than the recommended value.

Table 3. Industrial sector vs. job position

Job Position	Industrial sector										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Manager	20	2	1	7	1	2	5	0	0	12	50
Engineer	60	2	9	24	6	3	30	5	2	15	156
Supervisor	19	1	3	10	2	2	10	2	0	11	60
Technician	19	0	2	7	2	4	14	1	0	9	58
Other	30	0	1	8	4	2	13	0	1	28	87
Total	148	5	16	56	15	13	72	8	3	75	411

+1-Automotive; 2 - Aeronautics; 3 - Electric; 4 - Electronics; 5 - Logistics; 6 - Machining; 7 - Medical; 8 - Rubber and Plastics; 9 - Textile and Clothing; 10 - Other

Table 4. Company size vs. Years of experience.

Company Size	Years of experience					
	0 to <1	1 to <2	2 to <5	5 to <10	>10	Total
<50	3	4	8	6	6	27
50 to <300	4	5	16	9	12	46
300 to <1000	5	12	28	30	14	89
1000 < to 5000	5	19	56	36	31	147
5000 to <10000	4	12	18	11	9	54
>10000	2	8	13	11	14	48
Total	23	60	139	103	86	411

Table 5. Validation indices

Index	Proposed model					Feedback model					Best if
	JIT	**KAI**	**TQM**	**TPM**	**SOS**	**JIT**	**KAI**	**TQM**	**TPM**	**SOS**	
R^2	0.508		0.340	0.375	0.447	0.352	0.433	0.546	0.337		≥0.02
Adj. R^2	0.504		0.337	0.373	0.444	0.350	0.429	0.544	0.334		≥0.02
Composite reliability	0.907	0.881	0.933	0.935	0.959	0.907	0.881	0.933	0.935	0.959	≥0.7
Cronbach's alpha	0.846	0.831	0.904	0.907	0.949	0.846	0.831	0.904	0.907	0.949	≥0.7
Avg. var. Extrac (AVE)	0.765	0.598	0.777	0.782	0.797	0.765	0.598	0.777	0.782	0.797	≥0.5
Full. Collin. VIF	2.114	1.756	2.143	1.897	1.907	2.114	1.756	2.143	1.897	1.907	≤3.3
Q-squared	0.508		0.338	0.374	0.447	0.353	0.433	0.546	0.337		≥0
Normal-JB	No	No	No	No	No	No	No	No	No	No	

Table 6. Model efficiency indexes

Indexes	Model proposed	Model of feedback	Better if
APC	0.353, p<0.001	0.352, p<0.001	p<0.001
ARS	0.417, p<0.001	0.417, p<0.001	p<0.001
AARS	0.415, p<0.001	0.414, p<0.001	p<0.001
AVIF	1.680	1.747	<3.3
AFVIF	1.963	1.963	<3.3
GoF	0.557	0.557	>0

4.4. Structural Equation Modeling

Once both the proposed and the feedback SEM are evaluated, the outputs shown in Figures 5 and Figure 6 are obtained, where the values of the direct effects (β) or influences (arrows) of one variable on another are observed, and the p-value indicates that all are statistically significant at a 95% confidence level. Also, the effect size (ES) is indicated as a measure of the variance explained by the independent variable on the dependent variable, and, finally, the R^2 is also shown for each dependent variable. For example, KAI explains 14.2% (ES=0.142) of the variance of TQM, but together with TPM, it can explain 34.0% (R^2 =0.34).

Table 7 shows the indirect effects that occur between the variables and that reflect the indirect influence of an independent variable on a dependent variable through mediating variables, which were significant at a 99% confidence level. In this sense, it can be observed that, in the proposed model, *KAI* does not directly affect*SOS* but influences the latter through JIT, TQM and TPM with an effect size β=0.374 and explains a variability of ES=0.178. TPM also does not directly affect SOS; however, it indirectly affects it with a size of β=0.279 with an ES=0.140.

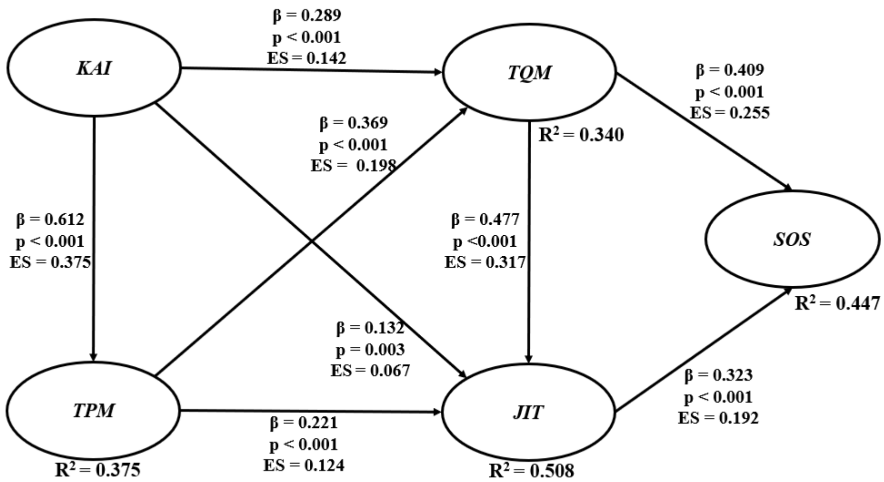

Figure 5. Proposed model evaluated

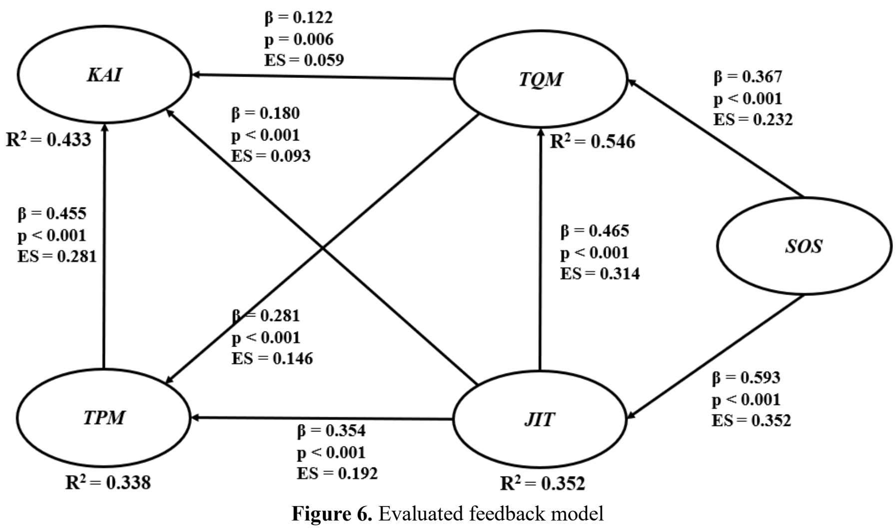

Figure 6. Evaluated feedback model

Table 7. The sum of indirect effects

Proposed model				Feedback model			
From/To	**JIT**	**TQM**	**SOS**	**From/To**	**KAI**	**TQM**	**TPM**
KAI	β=0.379 EN=0.193	β=0.226 EN=0.113	β=0.374 EN=0.178	**JIT**	β=0.277 EN=0.143	β=0.128 EN=0.071	β=0.363 EN=0.173
TQM			β=0.154 EN=0.096	**TQM**			β=0.276 ES=0.175
TPM	β=0.176 ES=0.098		β=0.279 EN=0.140	**SOS**	β=0.131 ES=0.062		β=0.391 EN=0.196

Table 8 illustrates the total effects (sum of direct and indirect effects), which were statistically significant at the 99% confidence level. It is observed that JIT has a total effect on SOS of 0.323, which is equal to the indirect effect since it has no direct effect.

The objective of using SEM is to find the effect sizes (β) of the causal relationships and the weights of the items (*w*) for use in system dynamics modeling to observe the behavior of the variables over time. Table 9 in the first column presents each of the established relationships. The second column shows the size of this relationship, called regression coefficient (β).Columns three and five show the components of each latent variable with its items. In contrast, columns four and six indicate the weights of the items in the independent variable.

4.5. System Dynamics Model Development

Figure 7 presents the feedback CLD conformed by the relationships established and validated in Figures 5 and 6 and fed by the regression coefficients (RC) and indicator weights shown in Table 9. Five feedback loops from B1 - B5 are shown, one for each variable. The blue arrows represent the indicator weights for each variable representing the reinforcement loops, so the "+" sign denotes them. The black arrows represent the causal relationships or hypotheses established.

Table 8. The sum of the total effects

Proposed model					Feedback model				
From/To	**JIT**	**TQM**	**TPM**	**SOS**	**From/To**	**KAI**	**TQM**	**TPM**	**JIT**
JIT				β=0.323 EN=0.192	**JIT**	β=0.458 ES=0.235	β=0.465 EN=0.314	β=0.484 EN=0.262	
KAI	β=0.511 EN=0.261	β=0.510 EN=0.256	β=0.610 ES=0.375	β=0.374 EN=0.178	**TQM**	β=0.250 EN=0.121		β=0.281 EN=0.146	
TQM	β=0.477 EN=0.317			β=0.563 EN=0.351	**TPM**	β=0.455 EN=0.281			
TPM	β=0.397 EN=0.222	β=0.369 EN=0.198		β=0.279 EN=0.140	**SOS**	β=0.363 EN=0.352	β=0.643 EN=0.173	β=0.391 EN=0.407	β=0.593 EN=0.196

Table 9. Regression coefficients and indicator weights.

Relationship	β	Relationship	Weights	Relationship	Weights
KAI→TQM	0.289	JIT5 → JIT	0.374	SOS1 → SOS	0.185
KAI→TPM	0.612	JIT6 → JIT	0.388	SOS2 → SOS	0.184
KAI→JIT	0.132	JIT7 → JIT	0.382	SOS3 → SOS	0.190
TPM→TQM	0.369	KAI1 → KAI	0.246	SOS4 → SOS	0.192
TPM→JIT	0.221	KAI3 → KAI	0.237	SOS5 → SOS	0.191
TQM→JIT	0.477	KAI5 → KAI	0.272	SOS6 → SOS	0.179
TQM→SOS	0.409	KAI6 → KAI	0.253		
JIT→SOS	0.323	KAI7 → KAI	0.282		
SOS→TQM	0.367	TQM1 → TQM	0.272		
SOS→JIT	0.593	TQM4 → TQM	0.282		
JIT→TQM	0.465	TQM5 → TQM	0.291		
JIT→KAI	0.180	TQM6 → TQM	0.289		
JIT→TPM	0.354	TPM1 → TPM	0.290		
TQM→TPM	0.281	TPM2 → TPM	0.290		
TQM→KAI	0.122	TPM3 → TPM	0.280		
TPM→KAI	0.455	TPM5 → TPM	0.271		

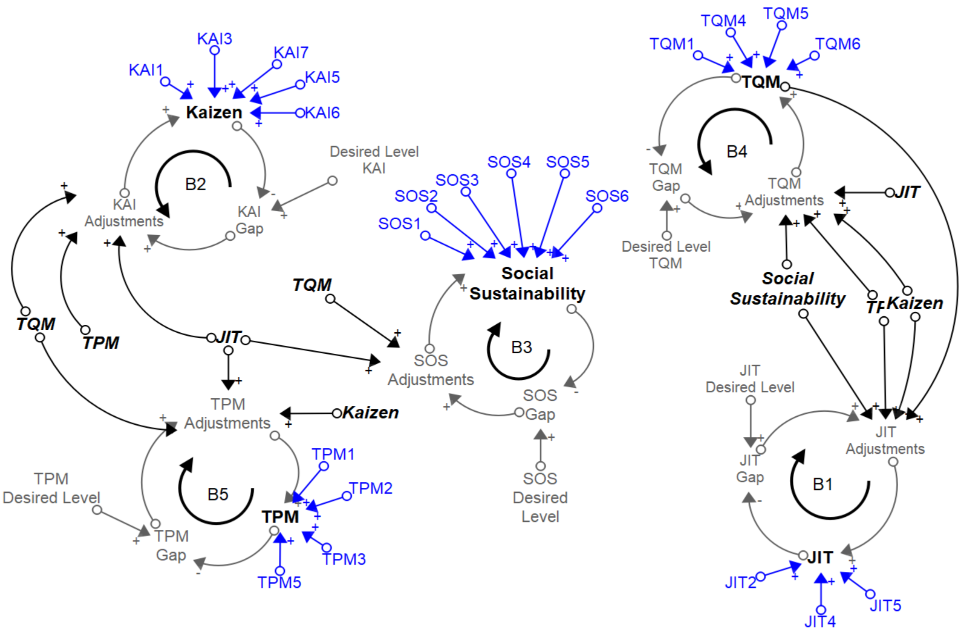

Figure 7. Diagram of causal feedback loop

To simulate the model and to be able to track the level of implementation of the LM tools and the achievement of the SOS, the variables in gray were added. These represent the *desired level* of implementation for each tool, the *adjustments* that companies must make to reach that *desired level* and the existing *gap* for companies to reach that *desired level.*

In other words, if companies want to achieve 100% implementation of their LM tools in their processes, and in a certain period they have only implemented 20%, the *Gap* will be 80%, and the adjustments they will have to make will be significant to achieve the *desired level* of 100%. Therefore, it was established that the higher the desired level, the more minor the adjustments will be; therefore, the *Gap* (with a "- " sign) will also be smaller. The above can be seen by the gray arrows for each variable's feedback loop. The same process is followed for each tool.

4.6. Equations

Once the CLD is defined, the next step is to establish a set of equations to be used in the simulation model, which allows the analysis and visualization of the behavior of the variables over time. The proposed equations are as follows:

- *Kaizen (KAI)* is the latent variable that analyzes the level of Kaizen implementation within companies and is defined by equation 1:

$$KAI_t = KAI_{t=0} + \int_0^t (AKAI)dt \tag{1}$$

$$AKAI = GKAI\left[\begin{array}{c}(RC_{TPM\to KAI} * TPM) * \sum_{i=1}^{5} wKAI_i + \left(RC_{TQM\to KAI}TQM\right) * \sum_{i=1}^{5} wKAI_i + \\ (RC_{JIT\to KAI} * JIT) * \sum_{i=1}^{5} wKAI_i\end{array}\right] \tag{2}$$

AKAI represents the adjustment in the activities in KAI and is defined by the multiplication of the regression coefficients (RC) of the variables that influence it and the sum of the weights (w) of the indicators in question.

GKAI represents the difference (*Gap*) between the desired level of Kaizen implementation within companies and the percentage of implementation in a given time.

- Equations 3 and 4 *describe* the behavior in the implementation of the variable TPM

$$TPM_t = TPM_{t=0} + \int_0^t (ATPM)dt \tag{3}$$

$$ATPM = GTPM\left[\begin{array}{c}(RC_{TQM\to TPM} * TQM) * \sum_{J=1}^{4} wTPM_J + (RC_{JIT\to TPM} * JIT) * \sum_{J=1}^{4} wTPM_J + \\ (RC_{KAI\to TPM} * KAI) * \sum_{J=1}^{4} wTPM_J\end{array}\right] \tag{4}$$

- Equations 5 and 6 describe the behavior of the TQM implementation.

$$TQM_t = TQM_{t=0} + \int_0^t (ATQM)dt \tag{5}$$

$$ATQM = GTQM\left[\begin{array}{c}(RC_{JIT\to TQM} * JIT) * \sum_{k=1}^{4} wTQM_k + (RC_{KAI\to TQM} * KAI) * \sum_{k=1}^{3} wTQM_k + \\ (RC_{TPM\to TQM} * TPM) * \sum_{k=1}^{3} wTQM_k + (RC_{SOS\to TQM} * SOS) * \sum_{k=1}^{3} wTQM_k\end{array}\right] \tag{6}$$

$$JIT_t = JIT + \int_0^t (AJIT)dt \tag{7}$$

$$AJIT = GJIT\left[\begin{array}{c}\left(RC_{TPM\to JIT} * TPM\right) * \sum_{l=1}^{3} wJIT_l + \left(RC_{TQM\to JIT} * TQM\right) * \sum_{l=1}^{3} wJIT_l + \\ \left(RC_{KAI\to JIT} * KAI\right) * \sum_{l=1}^{3} JIT_l + (RC_{SOS\to JIT} * SOS) * \sum_{l=1}^{3} wTQM_l\end{array}\right] \tag{8}$$

- Finally, equations 9 and 10 describe the behavior of the *Social Sustainability (SOS)* variable.

$$SOS = SOS_{t=0} + \int_0^t (ASOS)\, dt \tag{9}$$

$$ASOS = GSOS\left[(RC_{TQM\to SOS} * TQM) * \sum_{m=1}^{6} wSOS_m + (RC_{JIT\to SOS} *) * \sum_{m=1}^{6} wSOS_m\right] \tag{10}$$

4.7. Initial parameters

Figure 8 corresponds to the causal loop diagram programmed in the STELLA ARCHITECT V3.03 software. The water tanks represent the settings made in each of the LM tools. These tanks are fed by the indicator weights of each variable denoted by blue arrows. In addition, it is fed by the latent variables that influence the variable in question (black arrows) and the *Gap*,which, in turn, is influenced by the same variable and the *desired level*, denoted by gray arrows.

The simulation was conducted by establishing initial parameters to create a starting scenario, predict the time required to achieve the desired implementation level, and analyze the system's behavior across various conditions. The simulation spanned five years, taking into account that many involved companies are sizable, and the assimilation of a philosophy like JIT typically demands substantial time to become fully integrated into their operational culture.

The initial values shown in Table 10 were established. An initial value of 0.1 means that the companies already have 10% implementation of the LMTs and SOS. The aim is to investigate the time at which this level of implementation will be 100%. Therefore, different initial values (between 0 and 1) can be set to analyze the behavior in these scenarios. Thus, 0 represents zero implementation in the development of the activities, and 1 represents that 100% has been achieved.

Table 10. Initial values and desired level for each variable

Latent and auxiliary variables	Initial value
Just in time (JIT)	0.1
Kaizen (KAI)	0.1
Total Quality Management (TQM)	0.1
Total Productive Maintenance (TPM)	0.1
Social Sustainability (SOS)	0.1
Desired Level JIT	1
Desired Level KAI	1
Desired Level TQM	1
Desired Level TPM	1
Desired Level SOS	1

4.8. Evaluation of the simulation model

Figure 9 shows the simulated model using the initial values in Table 10. It was assumed that the companies had 10% implementation for each tool and achieved 10% SOS. Positive flows are shown with red arrows, and negative flows are shown with blue arrows. In this case, the variables negatively influence the *Gap,* indicating that the greater the level of implementation of each tool, the smaller the *Gap; however,* the greater the *Gap, the greater the adjustments* will have to be to achieve the *desired level* of 100%.

Figure 10 shows the percentage of SOS obtained by the companies in five years if the initial values were 10% for each tool. The companies will have achieved 93.9% of the SOS, with only 6.1% remaining to reach the desired level.

Figure 11 shows that JIT will have reached 100% implementation, Kaizen 95.5%, TQM 99.6%, TPM 98.9% and SOS 93.9%. The above indicates that it can be considered that the LMTs analyzed will be almost entirely implemented in 5 years.

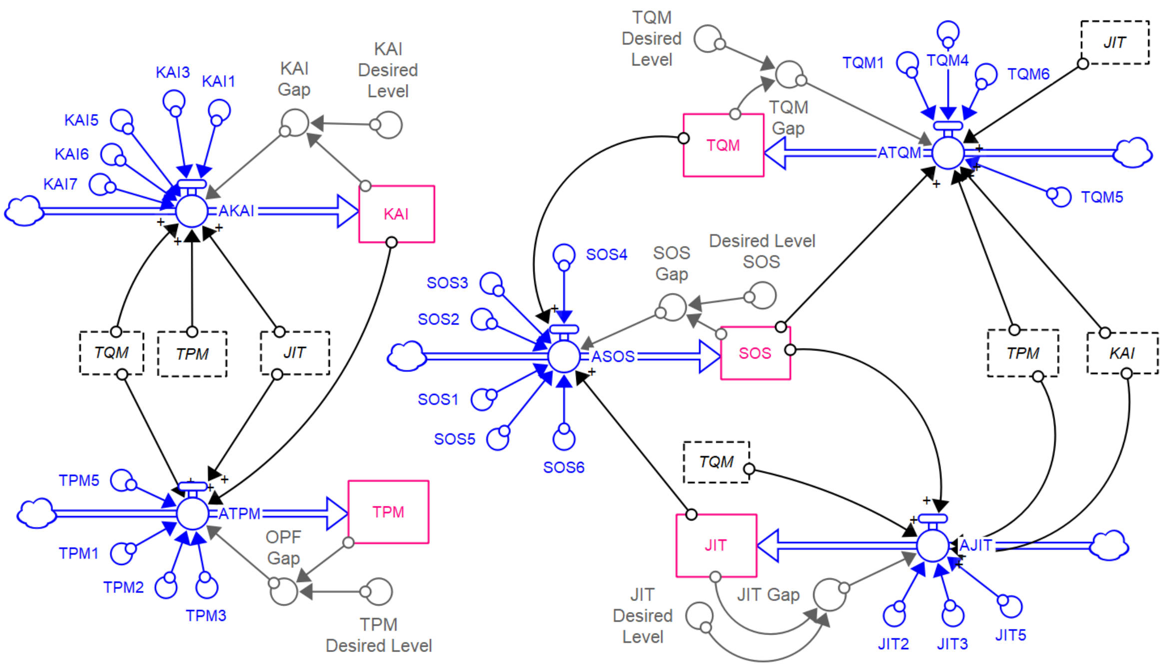

Figure 8. The model simulated in STELLA ARCHITECT® V3.03 Software

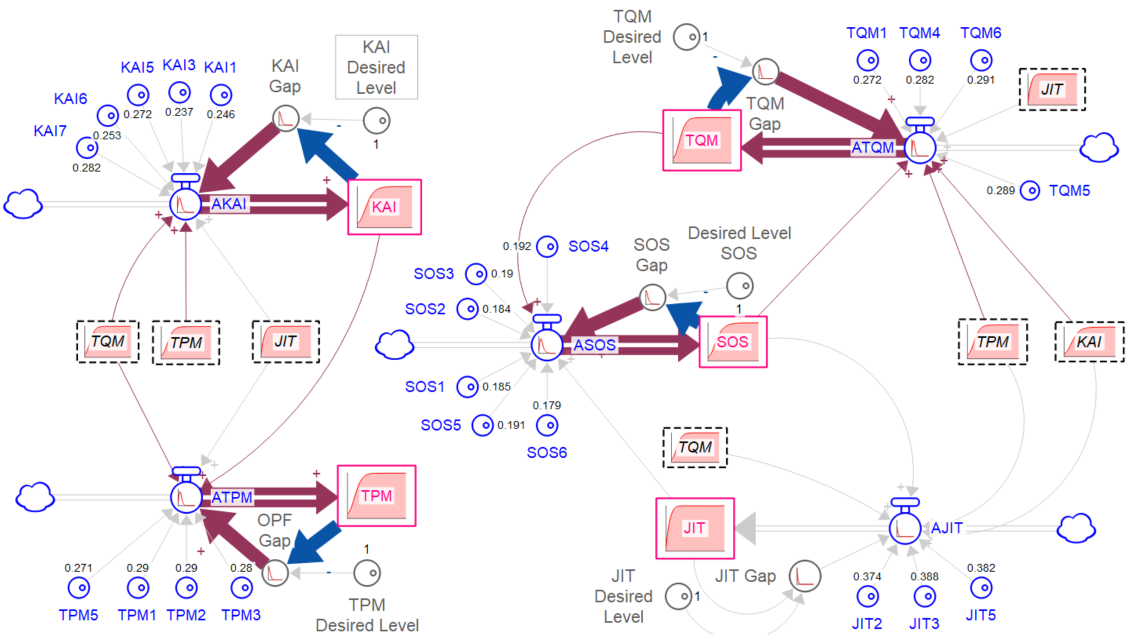

Figure 9. Simulated Causal Loop Model

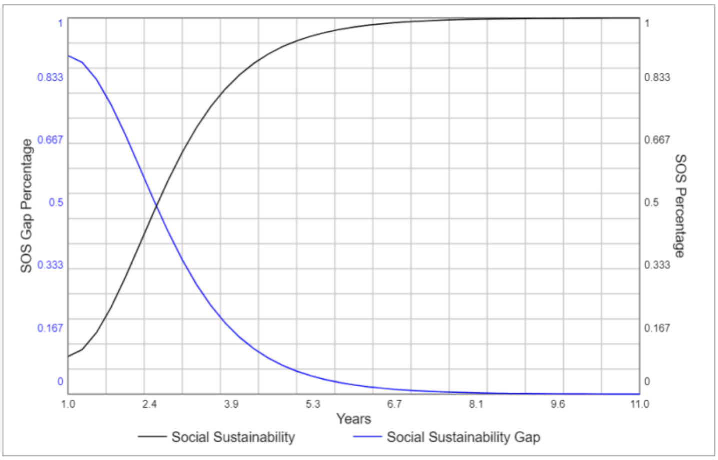

Figure 10. Percentage of Social Sustainability achieved in 5 years

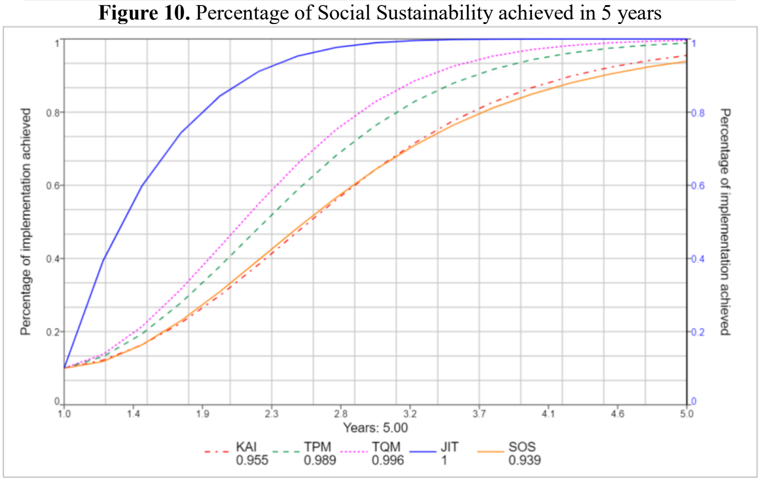

Figure 11. Level of implementation for each tool in five years

Determining the precise time needed to achieve 100% implementation of each LMT and understanding the SOS scope is essential; that is why the period was extended to 11 years to observe the behavior of each variable. JIT will reach the desired level in 4 years (Figure 12.ATime to desired level of JIT), TQM in 6 years (Figure 12.bTime to the desired level of TQM), TPM in 7 years (Figure 12.cTime to the desired level of TPM), Kaizen in 9.25 years (Figure 12.dTime to desired level of Kaizen) and SOS in 10.25 years (Figure 12.e. Time to the desired level of Social Sustainability).

Figure 13 illustrates the scenarios simulated to observe the behavior of LMTs and SOS. For each scenario, initial implementation values were established for each tool; for example, Figure 13.a shows that if the companies have 25% implementation of LMT and SOS, after five years, they will have achieved 100% JIT, 97.7% KAI, 99.9% TQM and TPM, and 96.3% SOS. Figures 13.a to 13.d show each simulated scenario's initial values and percentages achieved in 5 years. If any reader wishes to perform the simulation for different levels of the initial implementation of the analyzed variables not simulated in this document, please consult the following link:https://exchange.iseesystems.com/public/jose-roberto-diaz-reza/social-sustainability-through-lean-manufacturing-diaz-reza-et-al/index.html#page1, where users have the option to adjust the desired levels and initiate the simulation manually.

The Figure 13 shows the scenarios in which different initial values are set to observe Lean management's and TQM tools' behavior. In that sense, with an initial value of 0.25 for JIT, TQM and SOS and 0.5 for KAI and TPM, the percentages shown in Figure 13.a will be reached.

Figure 13.b shows the initial values of 0.5 for each variable. Figure 13.c shows initial values of 0.5 for TQM, JIT and SOS and 0.75 for KAI and TPM. Finally, Figure 13.d shows initial values of 0.75 for all variables.

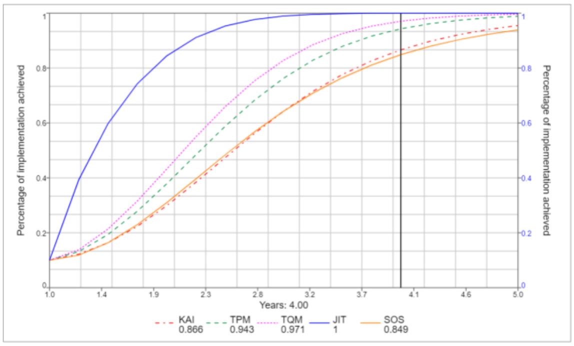

Figure 12.a

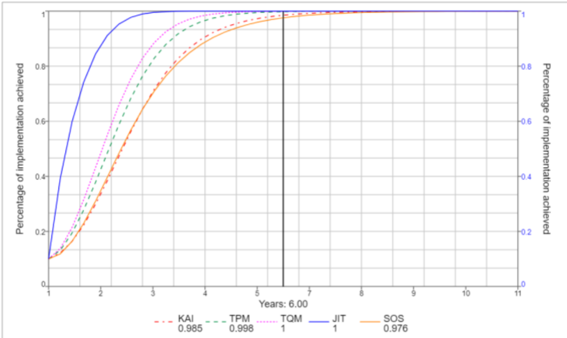

Figure 12.b

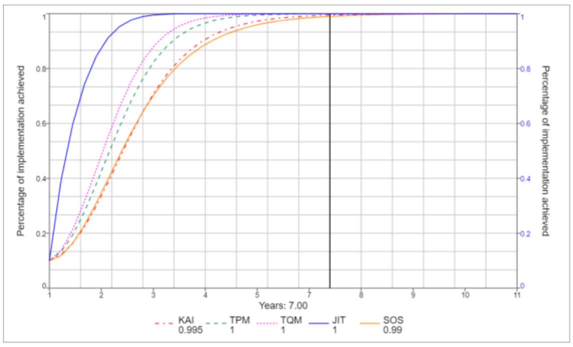

Figure 12.c

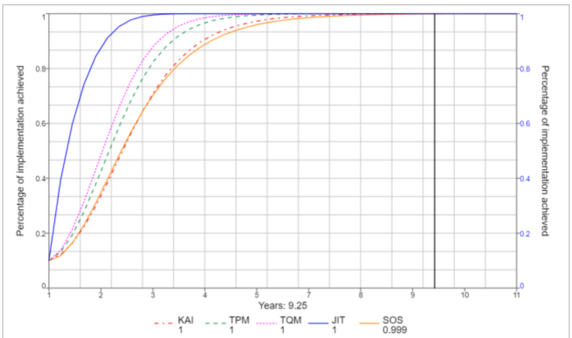

Figure 12.d

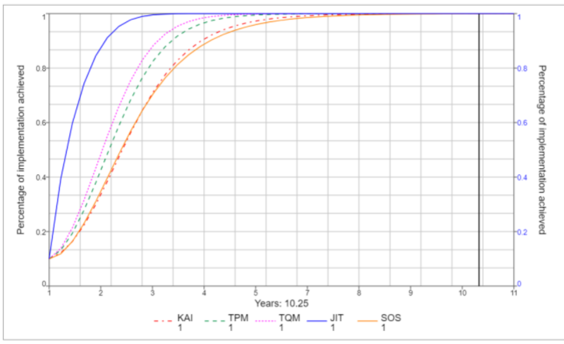

Figure 12.e

Figure 12. Time to reach the desired level for each LM and SOS tool.

5. Conclusions and Discussion

5.1. Structural Equation Model

From the results of the structural equation models, it can be concluded that all hypotheses are statistically significant, so there is a direct and positive effect of the latent independent variables on the latent dependent variables in each of the established relationships.

Individually, the following conclusions can be drawn from Figure 5:

- KAI has a direct and positive effect on TPM, TQM, and JIT of size β=0.612, β=0.289 and β=0.132, respectively, and with ES of 0.375, 0.142,and 0.067 of the variability of these variables, respectively. The above indicates the importance of a Kaizen philosophy within the companies, as it facilitates techniques such as TPM, TQM and JIT. The above is consistent with what Guedes, Figueiredo [40]concluded. There is evidence that TPM improves innovation performance and that the impact of TPM on innovation performance increases with the mediating effect of Kaizen events. As well as mentioned by Abidin, Leman [41]highlighted the significant relationship between Kaizen and JIT on the impact of inventory reduction, leading to further productivity improvement. Likewise, Maware, Okwu [42]found that Kaizen positively impacted environmental performance, an essential aspect of TQM.The above indicates that if companies work through a continuous improvement philosophy, implementing tools such as TPM will be facilitated by maximizing equipment efficiency and reducing downtime. In addition, Kaizen positively affects TQM as it improves productivity, sales volume, and customer satisfaction, among other things. In the same way, Kaizen contributes positively to JIT by reducing in-process inventories, material flow efficiency, and waste reduction, among others.
- TPM is also a direct enabler of TQM and JIT since it has a direct and positive effect size of β=0.369 and β=0.132 with ES of 0.198 and 0.067, respectively. Lo que concuerda con lo encontrado por Singh and Singh Ahuja [43]que, ilustraron cómo la relación sinérgica de TPM y TQM puede mejorar el rendimiento empresarial global. Likewise, Khalfallah and Lakhal [44]found a positive impact of TPM on JIT, indicating that TPM facilitates JIT implementation.The above indicates that, by implementing TPM practices, organizations can improve operational performance, reduce costs, improve equipment performance, and achieve process and product quality. In addition, TPM practices have a positive relationship with JIT, as machine availability is crucial for JIT production, thus contributing to product quality, on-time deliveries, and flexibility in production volume.
- In the same way, TQM is a facilitator of JIT and, in addition, contributes to the well-being of workers, facilitating SOS within firms. TQM has a direct and positive effect on TPM and SOS of size β=0.477 and β=0.409 and explains 0.317 and 0.255 of the variability of these two variables, respectively. The above indicates thatif companies have work teams at different hierarchical levels to ensure quality and decision-making is justified with facts, focus on satisfying customer needs, and involve collaborators to manufacture a quality product, a JIT philosophy will facilitate the work through the reduction of inventory levels, waste, improvement of the flow of materials, among others. Likewise, implementing TQM promotes SOS within companies by improving working conditions, safety, health, employee morale, and social pressure.This is in agreement with the finding of Phan, Nguyen [45], who indicated that a higher level of TQM can reinforce the effect of JIT production practices on flexibility performance.

Finally, *JIT* directly and positively affects *SOS* of size β=0.323 with ES of 0.192. In that sense, working through a JIT philosophy will also favor SOS within companies, which is consistent with [22], who indicated that JIT tools significantly influences organizational performance, demonstrating its potential to improve sustainability. Ismail Salaheldin [46]provided empirical evidence of the association between JIT success and human resource modification efforts, indicating the social implications of JIT implementation in manufacturing firms. This is consistent with Phan, Nguyen [45]that delved into plant managers' attitudes towards sustainability and its relation to operational performance, emphasizing the importance of considering social and environmental aspects in measuring organizational performance.

In that sense, integrating practices such as KAI, TPM, JIT and TQM can contribute to sustainable performance in the manufacturing industry by improving working conditions and providing safe workplaces while improving employee health and morale.

5.2. System Dynamics Model

Regarding the System Dynamics model, the following conclusions can be drawn:

- Achieving a social sustainability culture within companies is not easy or quick; it is a constant task for everyone involved. However, LMTs contribute significantly to achieving a socially sustainable culture in the medium term to achieve sustainability in the long term. Withinfiveyears, JIT will be the only one to reach 100% implementation, KAI at 95.5%, TQM at 99.6%, TPM at 98.9% and SOS at 93.9%. The above indicates that achieving this desired level will be reached after five years.
- If the simulation period is extended, the desired level of implementation for each tool will be completed in 9.25 years, and SOS at its desired level will be reached in 10.25 years. This assumes that these tools have a 10% implementation rate in the companies and that the SOS is 10%. However, if there were a 25% level of implementation of LMTs, practically in 5 years, the desired level would be obtained in 100% in JIT, 99.9% in KAI, 99.9% in TQM and 99.6% in TPM and 98.2% in SOS.
- If scenarios are established where an implementation level of 50% is achieved, 100% implementation will have been reached for JIT, KAI, and TQM, 99.9% for TPM, and 98.2% for SOS.

- When initial implementation levels are set at 75% for the tools and SOS, 100% attainment is projected for each tool, while 99.3% is anticipated for SOS.

In this sense, and as mentioned above, SOS is not an easy task, and it is only achieved after a period, even with high levels of implementation in LM tools, so a working culture must be established daily, considering the needs of workers.

Industrial implications

- The successful application of Lean Management (LM), with tools such as Kaizen and philosophies such as Total Quality Management, can significantly impact social sustainability in manufacturing companies.
- The emphasis on continuous improvement is essential to achieve social sustainability, acting as an enabler to implement tools such as TPM, TQM and JIT. It is projected that 100% implementation of these tools will be achieved in 7 years and full social sustainability in 10.25 years.
- Adopting LM implies a cultural change, requiring managerial commitment and active participation of employees in continuous improvement. This practice can enhance corporate reputation by demonstrating a commitment to sustainability.
- While the focus is on social sustainability, LM process improvements can also reduce environmental impact, contributing to overall sustainability.

Theoretical Implication

This study can enrich the theoretical understanding of how management practices, such as Lean Management, influence corporate social sustainability. Using system dynamics models to assess these effects would contribute to understanding how these practices affect sustainability. In addition, highlighting continuous improvement as a driver of sustainability could contribute to organizational improvement theory. This analysis offers valuable insights into social sustainability in companies, contributing to developing theories on corporate sustainability and the influence of specific LM tools on business and social outcomes.

Limitations

- The findings are based primarily on data collected from companies in the automotive sector with more than 1,000 employees, which may limit their applicability to other sectors or smaller companies due to differences in dynamics and challenges.
-
- The data collection focuses on specific companies, which could introduce biases in the results due to concentration in a particular sector or specific selection criteria.
- The time projections for reaching 100% implementation of tools and total social sustainability are theoretical and model-based without considering possible variations in the business environment.
- Despite its value, the study focuses mainly on social sustainability, excluding aspects such as economic and environmental sustainability, which limits the entire understanding of corporate sustainability.
- The study may have yet to consider tools or methodologies that could influence LM implementation or social sustainability, limiting the breadth of the findings.
- Business and social conditions may vary between regions or countries, affecting the applicability of the results in other geographical contexts.

Future Work

- Broaden the analysis to include social, economic, and environmental sustainability, providing a holistic view of corporate sustainability and how Lean Management influences each dimension.
- Conduct comparative studies between companies in different countries to understand how cultural, political and economic differences influence the application of Lean Management and its impact on social sustainability.
- Explore how the integration of additional LM tools beyond those studied (Kaizen, TPM, TQM and JIT) could influence social sustainability. Investigate how practices such as Value Stream Mapping, 5S, and Kanban, among others, affect implementation and social sustainability in different business contexts.

Acknowledgments

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Appendix A. Variables definition

Variable/Activity	Description
KAI1	The person in charge is attentive to the way of working in their area
KAI3	During the day, do they take time in their work area?
KAI5	Have they implemented improvements in the processes with which you have contact?
KAI6	Annual percentage scraps show a declining trend.
KAI7	Labor productivity shows a rising trend over time.
TPM1	We ensure that machines are always in a high state of readiness for production.
TPM2	We dedicate periodic inspections to keep machines running.
TPM3	We have a daily maintenance sound system to prevent machine failure.
TPM5	We have time set aside each day for maintenance activities.
TQM1	We have work teams in which different hierarchical levels of the company participate to guarantee quality.
TQM4	Decision-making for improvement is justified with facts and data.
TQM5	The organization is focused on satisfying the customers' needs, involving the collaborators to achieve a quality product.
TQM6	There are clear quality plans and programs throughout the company.
JIT2	Internal material flow is efficient and continuous between operations.
JIT3	Product rework is reduced to an acceptable minimum.
JIT5	Material transportation is minimized.
SOS1	Improved working conditions
SOS2	Improved safety in the workplace
SOS3	Improved employee health
SOS4	Improved labor relations
SOS5	Improved morale
SOS6	Decrease in working pressure.