# Fluidity index for smart farms supply chain

# Índice de fluidez en cadenas agroalimentarias

Bueno-Solano, Alfredo*[a], Hernández-Valdez, Lizeth Danyra [b], Vega-Telles, Ernesto Alonso [c] and Acosta-Quintana, María Paz Guadalupe [d]

[a] ROR Instituto Tecnológico de Sonora • KVY-4884-2024• 0000-0001-5539-1924 • 293248
[b] ROR Instituto Tecnológico de Sonora • LBH-6538-2024• 0009-0007-2393-4171
[c] ROR Instituto Tecnológico de Sonora• LBH-6651-2024• 0000-0002-8260-3002 • 1179288
[d] ROR Instituto Tecnológico de Sonora • GLR-5880-2022• 0000-0001-7115-9076 • 249127

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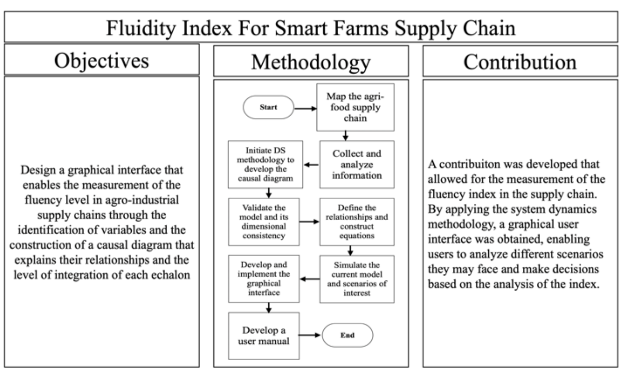
* ✉ [abuenosolano@itson.edu.mx]

**Abstract**

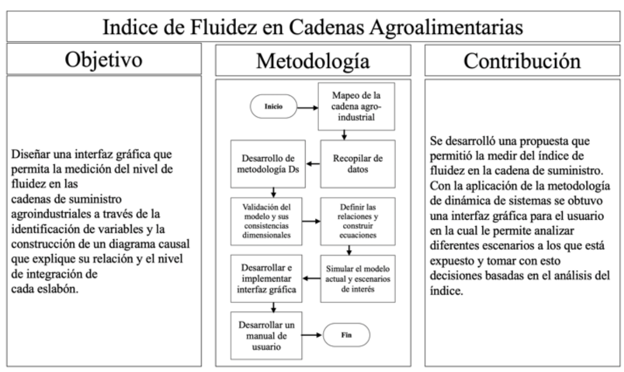
This research provides a comprehensive perspective on the supply chain of the agri-food sector in Sonora, Mexico, with a specific focus on tomatoes, one of the most prominent products in both the regional and national economy. The analysis emphasizes the importance of supply chain integration and its impact on the fluency index, utilizing system dynamics methodology to simulate and evaluate this influence.




**Smart Farms, Logistics, Fluidity Index**

**Resumen**

La presente investigación ofrece una perspectiva integral sobre la cadena de suministro del sector agroalimentario en Sonora, México, con un enfoque específico en el tomate, uno de los productos más destacados en la economía regional y nacional. El análisis se centra en la importancia de la integración de la cadena de suministro y su impacto en el índice de fluidez, utilizando la metodología de dinámica de sistemas para simular y evaluar dicha influencia.




**Agroindustria, Logística, Índice de Fluidez**

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## Introduction

The agri-food sector in Mexico is vital to the country's economy, significantly contributing to the Gross Domestic Product (GDP). In 2018, the primary sector contributed 2.4% to the national GDP, highlighting the relevance of activities such as agriculture, livestock, fishing, and forestry.

Sonora, in particular, has established itself as a leader in the export of agri-food products due to its vast territorial extension dedicated to cultivation and its ability to generate foreign exchange through these exports. In this context, the tomato stands out as a key product due to its production volume and economic value.

The analysis of the tomato supply chain in Sonora reveals several challenges and opportunities. Supply chain integration is identified as a crucial factor for improving the sector's efficiency and competitiveness. Integration allows better coordination of information, resources, and materials flows among the various actors in the chain, from producers to distributors and marketers. Bautista Santos and others (2015) define supply chain integration as the interrelation and alignment of internal and external processes and flows of companies to satisfy the customer efficiently.

Despite its importance, supply chain integration in the Mexican agri-food sector has significant deficiencies. Only 13% of organizations have an integrated system for synchronizing information and material delivery, limiting these chains' ability to operate efficiently and respond adequately to market demands. Implementing information tools and advanced technologies is crucial to improving this situation. According to the USAID Logistics Indicators Study (2014), organizations should focus on process management, technological advancements, chain collaboration, customer relations, and investment optimization to optimize their operations.

## Background

Fluidity in supply chains is another essential factor influencing their performance. Increasing fluidity improves the chain's reliability and responsiveness to market changes.

However, research on fluidity in supply chains is limited, leaving ample room for future studies. Implementing a fluidity index, as proposed by Cedillo Campos (2018), can provide a valuable tool for measuring and improving supply chain performance. This index helps identify the level of capacity achieved continuously and safely, which is essential for decision-making and efficient information management.

Fluidity can be defined as the level of capacity to achieve a reliable, safe, and accurate flow of physical, financial, human, and information resources over time, effectively supporting the supply chain's objectives. (Cedillo Campos, Lizarraga, Lizarraga & Martner Peyrelongue, 2019).

The integration of the supply chain and its ability to improve process fluidity can offer numerous benefits, including reducing uncertainty in decision-making, decreasing errors, eliminating non-value-adding activities, and increasing resource flow. (Bueno et al., 2022). Additionally, integration facilitates collaboration among different supply chains, which can lead to the creation of new business opportunities and economic development at regional, state, national, and even global levels.

A significant challenge organization currently face is achieving supply chain integration, where all components' flow is controlled. This integration applies to any industry sector, as they are affected by different variables, such as endogenous and exogenous factors.

Bautista Santos and others (2015) define supply chain integration as "a term that ranges from the interrelation of internal processes and flows of each company to the combination of processes and flows of multiple actors; where these processes are aligned based on the chain's strategy to satisfy the customer."

According to the USAID Logistics Indicators Study (2014), five main areas where organizations should focus to optimize supply chain operations are: process management, technological advancements, chain collaboration, customer relations, and investment optimization.

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The current situation of supply chains in the mentioned study reveals that only 13% of the organizations studied have an integrated system for synchronizing information and material delivery. This low percentage is influenced by the limited use of information tools, with 64% of companies doing so informally and/or in certain areas.

The integrated coordination within supply chains facilitates value creation, especially when demand and supply fluctuate rapidly and unpredictably. Phadnis and Schoemaker (2024).

However, to gain more information about the influence of supply chain integration on the fluidity index of the food sector, this research proposes designing a graphical interface to measure the fluidity level in agri-industrial supply chains by identifying variables and constructing a causal diagram that explains their relationship and the level of integration of each link, all using system dynamics as a tool to understand the relationships among all participants in the supply chain.

## Methodology

This section details the procedure or methodological route used in the research project on supply chains in the agri-food sector. Figure 1 below illustrates this.

Box 1

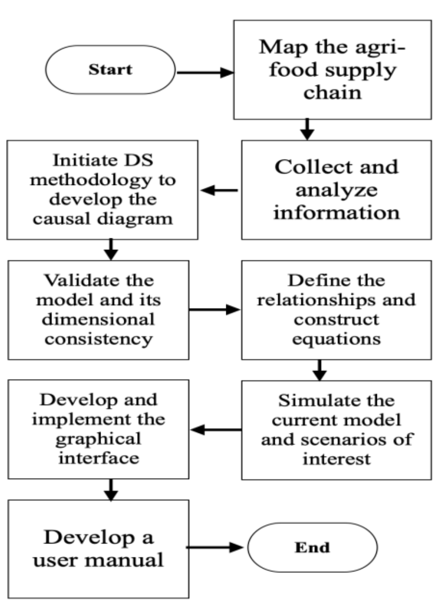


**Figure 1**
Research Project Procedure Flowchart

The stages of this procedure are explained below:

- **Mapping the Agri-Food Supply Chain**

Bibliographic searches and visits to organizations in northwestern Mexico will be conducted to determine the configuration of the agri-industrial supply chain, specifically identifying the elements involved in tomatoes.

- **Data Collection and Analysis**

For information collection, Google Maps will be used to indicate the departure location and destination of transported resources. This will identify the routes between different locations as well as traffic conditions.

- **Development of the Causal Diagram of the Supply Chain**

In this stage, a causal diagram will be created, a tool used in the early stages of system dynamics to graphically show cause-effect relationships between two or more variables. (Lagarda Leyva, 2019).

In causal diagrams, three types of relationships are presented: direct relationships, where a parameter affects a variable; simple relationships, where one variable affects another and is also influenced by it, possibly affected by a parameter; and complex relationships, where more than two variables affect each other.

Feedback loops occur when a simple or complex relationship arises between variables, which can be of two types: reinforcing or balancing, influenced by the type of polarity. A positive (+) polarity increases the other variable, while a negative (-) polarity decreases it.

- **Construction of the Forrester Diagram**

In this stage, the mathematical model is constructed following the system dynamics methodology with the Forrester diagram, which, according to Morlán Santa Catalina (2010), is "an intermediate step for obtaining the mathematical equations that define the system's behavior."

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- **Simulation of the Current Model**

Model ejection will be conducted using the Stella Architect software simulation based on the data obtained in the research on the current situation of the food sector supply chain.

- **Dimensional Consistency Verification**

A series of tables will be created to identify and classify the different types of variables in the system dynamics methodology, which are level, flow, and auxiliary variables. The procedure for validating consistency, according to Sterman (2000), involves "carefully reviewing that each equation and parameter in the model have consistency in their units to prevent errors during calculations in the simulation and avoid drawing erroneous conclusions about the system's behavior under study." Additionally, the units of each variable used in the model will be verified with an internal tool in the Stella Architect software.

- **Implementation and Communication of the Graphical Interface**

In this stage, a graphical interface was designed, consisting of a series of graphical elements that allow the user to communicate with the system. The interface design, according to Luna González (2004), requires "a theoretical foundation to discern each element that composes it and provide its solutions." Consequently, the graphical interface design was based on the Forrester diagram previously developed in the Stella Architect software.

**Results**

- **Mapping the Agri-Food Supply Chain**

In this stage, the agri-food sector's supply chain was designed, including the main elements such as links and their relationships. Figure 2 below illustrates this.

**Box 2**

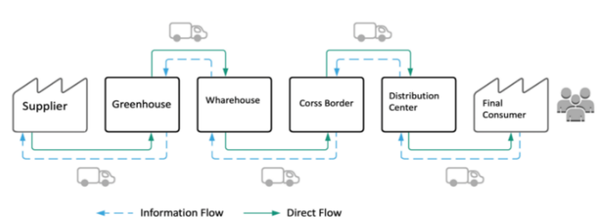


**Figure 2**

Agri-Food Supply Chain Mapping

The agri-food sector's supply chain starts with a raw material supplier, providing seeds, fertilizers, irrigation materials, etc., for cultivation, required by a greenhouse responsible for planting, growing, harvesting, and manually selecting the product. The product is then moved to an intermediate warehouse near the border for weighing, cleaning, and packaging.

The next step is customs, where the product undergoes inspections to meet standards before entering the country. The product is then transported to a distribution center for further distribution to various points of sale, eventually reaching the final consumer.

The supply chain works as a network where information and material flows. The greenhouse handles planting, growing, harvesting, and selecting the product, then moves it to an intermediate warehouse for weighing, cleaning, and packaging. The next step is customs, followed by distribution to various sales points, eventually reaching the final consumer. Information follows a process starting with product demand, inventory checks, order fulfillment, and customer approval, or ordering from the supplier if inventory is insufficient.

- **Data Collection and Analysis**

In this stage, Google Maps was used to determine transportation times between supply chain links. Figure 3 below illustrates an example.

**Box 3**

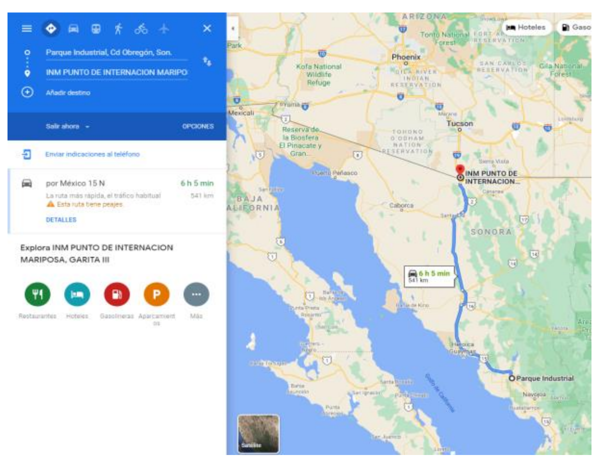


**Figure 3**

Inventory Transit to Customs Route

*Source: Google Maps 2020*

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The times and routes between different locations were recorded in the corresponding table. Table 1 below shows the routes studied for fluidity.

**Box 4**

**Table 1**

Studied Routes

| Process/Echalon | Route | Route Considered |
|---|---|---|
| Supplies | 1 | Bácum/Son 105 hacia calle base/128 |
| Cleaning and sorting (preparation to sent) | 2 | Blvd. Rodolfo Félix Valdez La Loma de Bácum, Son. |
| Washing and Packaging | 3 | Calzada Francisco Villanueva y Calle Sufragio Efectivo |
| In transit Inventory | 4 | Calzada Francisco Villanueva y Calle Sufragio Efectivo |
| Preparation to Cross an international Costumes | 5 | INM Punto de Internación Mariposa, Garita III Col del Rosario, 84020 Nogales, Son |
| Distribution center | 6 | Nogales, Arizona 85621, EE. UU. |

**Box 5**

**Table 2**

Transportation times in minutes for each process, morning shift, afternoon shift, night shift

| Route | Mornig | Afternoon | Night |
|---|---|---|---|
| 1 | 18 - 28 | 18-28 | --- |
| 2 | 3 | 3 | 3 |
| 3 | 24 - 45 | 26 - 40 | 28-50 |
| 4 | 15 – 60 | 15 – 60 | 15 – 60 |
| 5 | 340 - 430 | 340 - 450 | 380 |
| 6 | 14 – 18 | 14 - 18 | 14 - 18 |
| **TOTAL** | 496.5 | 507.5 | 465.5 |

Each table has routes, total distance, and delivery time, will be used to determine each link's fluidity index in the supply chain.

- **Development of the Causal Diagram of the Supply Chain**

The causal diagram was created with the identified variables and their relationships. Figure 4 below illustrates this.

**Box 6**

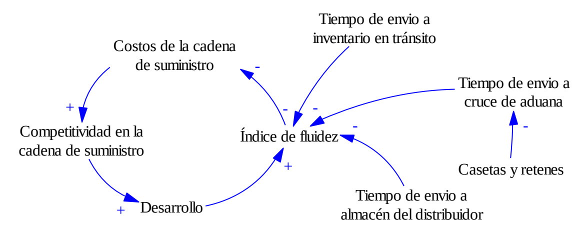


**Figure 4**

Tomato Supply Chain Causal Diagram

*Source: Own elaboration*

The causal diagram allows identifying the variables influencing the process and evaluating the relationships between them.

- **Construction of the Forrester Diagram**

The Forrester diagram was created in the Stella Architect software. Figure 5 below illustrates this.

**Box 7**

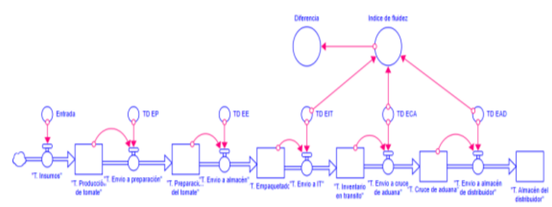

**Figure 5**

Forrester Diagram of the Tomato Supply Chain

*Source: Own elaboration*

The Forrester diagram defines each variable's role in the supply chain, from supplies to final delivery.

- **Simulation of the Current Model**

Model runs were conducted to simulate the current situation. Figure 7 shows the simulation run and validation. Also Table 3 below shows the results.

**Box 8**

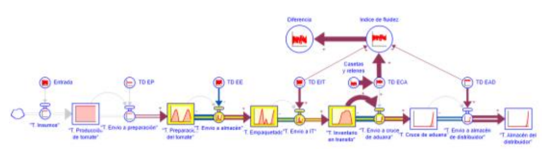

**Figure 6**

Results of simulation and validation process

*Source: Own elaboration*

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Figure 6 shows the model's behavior throughout the run, and the flow of resources through it can be observed. This verifies that the model's structure produces a result that approximates reality, in this case, the free-flow time.

For the search for inconsistencies, an analysis of extreme conditions and the resulting units of the designed model was carried out. The process began with the use of the software, which is illustrated in Figure 7 below.

**Box 9**

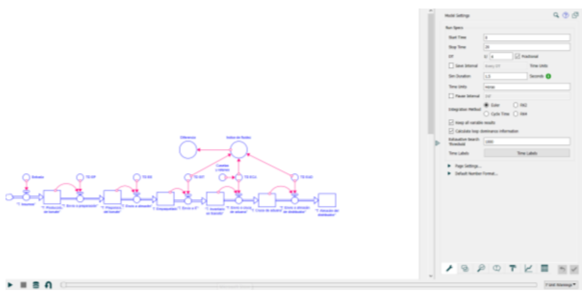

**Figure 7**
Consistency Validation

*Source: Own elaboration*

- **Implementation and Communication of the Graphical Interface**

The graphical interface was designed, allowing users to interact with the system. Figure 8 below illustrates this.

**Box 10**


**Figure 8**
Graphical Interface of the Tomato Supply Chain

*Source: Own elaboration*

As shown in Figure 8, the graphical interface menu contains five buttons, which, when clicked, direct you to a tab with the selected scenario or condition. Among these scenarios are three: the development of the model in the morning, afternoon, and night shifts.

The situations include being subject to a specific shift, which means it is a general model, and the scenario where an unplanned delay occurs, such as checkpoints, toll booths, and off-route inspections. This tab also includes two buttons to move forward or backward, similar to those used on previous pages.

For the situation where the process develops normally, without any particular condition, a tab was designed, which is shown in Figure 9 below.

**Box 11**

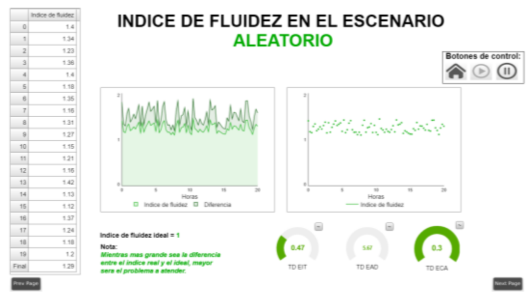


**Figure 9**
Model in general scenario of graphical interface

*Source: Own elaboration*

In Figure 9, the model for calculating the fluidity index is shown when no specific scenario is desired to be represented or when it is not subject to any particular situation.

The table inserted in the tab displays the results of the fluidity index calculated randomly twenty times. Additionally, two graphs can be observed: the first one shows two variables that aim to indicate the difference between the ideal value of the fluidity index and the resulting real value, while the second graph shows the distribution of the fluidity index results.

This tab also includes three knobs that function as control levers for the variables determining the fluidity index, specifically the time in hours between the links of packaging, inventory in transit, customs clearance, and distributor warehouse.

Following this, Figure 10 shows another screen of the graphical interface, where the user can analyze the previously discussed scenarios.



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**Box 12**

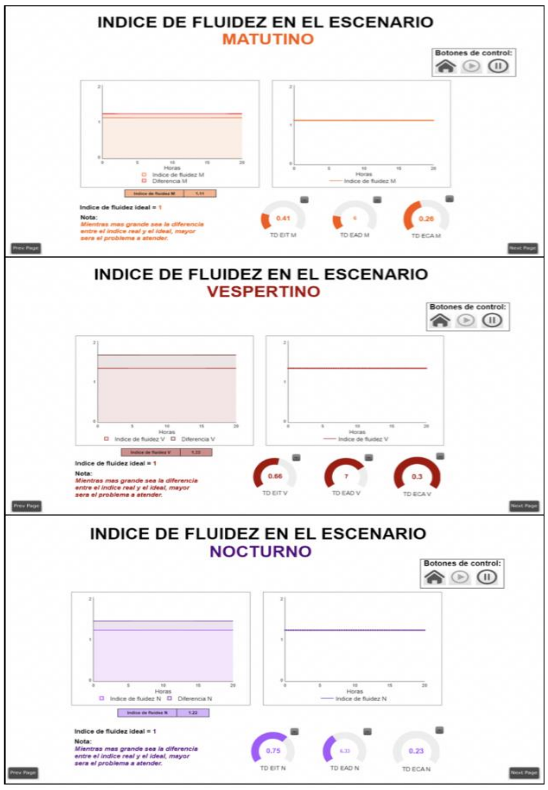


**Figure 10**
Graphical Interface of scenarios
*Source: Own elaboration*

In Figure 10, there is a screen where, for each shift under analysis, two graphs can be observed. The one on the top corresponds to the current calculated system fluidity index, while the second graph visually represents the difference between the current index and the ideal value.

This is influenced by three parameters corresponding to the time elapsed between the links, which, in this case, remain fixed since these values were obtained during the research for the morning shift.

The fluidity index given by the system should be equal to or as close as possible to the ideal; otherwise, there is an issue present. The screen also includes control buttons for managing the graphical interface.

Since only free flow is considered, the fluidity index is 100% in all cases as the programmed time is met.

In the following Figure 11, there is a screen of the graphical interface where two additional parameters were included to analyze the behavior when a series of exogenous events occur.

**Box 13**

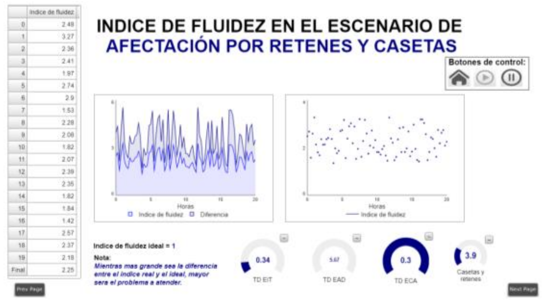


**Figure 11**
Graphical Interface of scenarios that present disruptions in the trip
*Source: Own elaboration*

In Figure 11, there is a screen of the graphical interface that includes the logic of the first model plus the inclusion of two variables: the time spent at toll booths and military or inspection checkpoints.

These have an influence when the shipment is sent for customs clearance. On the left side of the figure, there is a table with the times in minutes that it takes to cross all the stopping points along the route and, as a consequence, a significant decrease in the fluidity level measurement due to these variables.

This type of graph allows the user to observe the highest possible values of the difference between the fluidity index. It shows a decrease from 100% during free-flow conditions to 87% when considering toll booths and sanitary inspections.

- **Documentation and Continuous Improvement**

The final phase of the proposed methodology involves the documentation of the system's usage and the implementation of continuous improvement.

As mentioned earlier, this part is carried out by the model designers and the stakeholders, through the identification of areas of opportunity or the inclusion of new variables that may intervene in the future. It is always important to conduct an analysis process that allows for the updating of the model's variables and parameters, as well as the graphical interface, so that the user can access relevant information. This work should be done cyclically and repeated, as there is always room for improvement.

**Conclusions**

In this research project, a proposal was developed for a tool that allows the measurement of the fluidity index in the agri-food supply chain focused on the tomato export process with the objective of answering the question: How does the integration of the supply chain influence the fluidity index of the food sector?

As a result of applying the system dynamics methodology, a graphical interface was obtained for the user, allowing the analysis of different scenarios to which the fluidity index measurement is exposed and making decisions based on the index analysis. The graphical interface was developed with the help of Stella Architect software.

Analyzing the proposed scenarios of the fluidity index calculation model in the food sector supply chain, it was determined that although none of these scenarios meet an ideal fluidity index equal to one, some are close to achieving it. Conversely, others are significantly far from the ideal due to the impact of exogenous variables beyond the control of the members of this supply chain.

One recommendation arising from the scenario analysis is the use of morning hours for product shipments, as the fluidity index values are closer to the ideal, with a difference of only 11% below it.

Another recommendation is to continue studying time reduction due to the nature of the product being handled and its shelf life after harvest to maintain the quality and safety of the tomatoes.

Finally, it is also recommended to use the Stella Architect software as it allows for various types of analyses in the supply chain links that aid in decision-making.

**Declarations**

**Conflict of interest**

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

**Authors' Contribution**

*Bueno-Solano Alfredo*: Contributed to the project idea, research method and technique.

*Acosta-Quintana Maria Paz:* Contributed to developed the background and methodology

*Vega-Telles Erneto A.*: Contribuite to the developed of the model and its validation

*Hernande- Valdez, Lizeth*.: Contibuite with the field work and developed de reach.

**Availability of data and materials**

Research data are available at alfredo.buenos@gmail.com, as well as can be estimated using google maps databases.

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**Referencias**

[1] Roldán., P.N. (2021). Cadena de suministro. Economipedia.com recupedo el 29 de enero de 2023

[2] Bautista Santos , H., Martínes Flores , J. L., Fernandéz Lambert , G., Bernabé Loranca, M. B., Sánchez Galván, F., & Sablón Cossio, N. (2015). Modelo de integración de cadenas de suministro colaborativas. *Dyna vol. 82*, 145 - 154.

[3] USAID MEXICO. (2014). Estudio de indicadores del desempeño logístico de las cadenas de suministro en México. México: Secretaría de Economía.