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A solution approach to the problem of selecting agricultural suppliers of fresh fruit supported by the process of hierarchical analysis and the system dynamics

Un enfoque de solución al problema de selección de proveedores agrícolas de fruta fresca apoyado en el proceso de análisis jerárquico y la dinámica de sistemas

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Resumen

La decisión de compra de fruto fresco que satisfaga criterios de exportación, es un problema complejo que impacta en la gestión eficiente de la cadena de suministro agroalimentaria. Si bien este tema ha sido abordado con suficiencia en la industria manufacturera y de servicios, los estudios en cadenas agroalimentarias han sido escasos y han ganado el interés de empresarios. Este artículo presenta un enfoque que integra el proceso de análisis jerárquico (AHP) con un modelo de dinámica de sistemas (SDM) para seleccionar proveedores agrícolas de fruta fresca. Se utilizan criterios del agricultor relacionados con la capacidad de suministro de fruta, la calidad histórica de la fruta entregada por el agricultor, y la velocidad de respuesta del agricultor para entregar la fruta solicitada por la empresa. El AHP ayuda a priorizar al proveedor que puede satisfacer la demanda en cuanto a cantidad y el calibre de la fruta requerida por el cliente, mientras que el SDM demuestra su utilidad para determinar la cantidad de fruta y secuencia del proveedor que debe ingresar al proceso de empaque. Los resultados se comparan con datos históricos reales de suministro de una empresa exportadora, y demuestran que la selección óptima del proveedor agrícola de fruta fresca, reduce el tiempo de ciclo de la jornada laboral para empaquetar el pedido del cliente y minimiza el nivel de inventario de fruta fresca. no solicitado por el mercado internacional. Si bien este enfoque ayuda a reducir el inventario de fruta fresca no-requerida para empaque, el SDM presenta la limitación de no predecir la cantidad de fruta en función de su tamaño de exportación, lo cual se resuelve con el AHP y el método de "Porcentaje de composición". Los elementos de información considerados en este enfoque de selección de proveedores agrícolas, facilitan su réplica en otros frutos similares.

Palabras clave: Simulación, Dinámica de Sistemas, Cadena de suministro, Lima persa.

Abstract

The decision process of purchasing fresh fruit that meets export criteria is a complex problem that directly involves the efficient management of the agri-food supply chain. Although this issue has been adequately addressed in the manufacturing and service industries, studies in agri-food chains have been scarce and therefore have gained the interest of entrepreneurs in that field. This article presents an approach that integrates the hierarchical analysis process (AHP) with a systems dynamics model (SDM) for selecting agricultural suppliers of fresh fruit. The included data consists of the farmer's criteria relating to the fruit supply capacity, the past recorded quality of the fruit delivered by the farmer, and the farmer’s responsiveness to deliver the fruit requested by the company. The AHP helps prioritize the supplier who can meet the demand in terms of quantity and size of fruit required by the customer, while the SDM demonstrates its usefulness in determining the quantity of fruit and sequence of the supplier that must enter the packaging process. The results are compared with real historical data of supply of an exporting company and demonstrate that the optimal selection of the agricultural supplier of fresh fruit, reduces cycle time workday for to pack the customer's order, and minimize the level of the inventory of fresh fruit not requested by the international market. While this approach help to reduce the inventory of fresh fruit not required for packaging, the SDM has the limitation of not predicting the quantity of fruit based on its export size. This problem is solved with the AHP and the "Composition Percentage" method. The fundamental information considered in this approach to the selection of agricultural suppliers facilitates its replication in other similar fruits.

Keywords: Simulation, Systems Dynamics, Supply Chain, Persian lime.

1. Introduction

Supplier agricultural suppliers’ selection is a strategic implementation for fruit-packing companies. It is a task that leads to an effective supply chain even before they start operations (Du et al., 2020). This is a complex activity that involves a large amount of resources, but effectively reduces costs, improves profits, reduces delivery times, and improves competitiveness (Taherdoost & Brard, 2019). This strategy is a multidimensional process involving quantitative and qualitative factors (Dai & Bai, 2020; Konys, 2019), with at least five stages: supplier identification, supplier evaluation, supplier feedback, and developing business partnerships (Shendryk et al., 2019). This activity is vitally important in determining how many and which vendors should be selected as supply sources and how order quantities should be allocated among the selected vendors (Tirkolaee et al., 2020).

Concerning the quantitative methods, there are a wide variety of approaches such as: data mining, optimization techniques, and Multi Criteria Decision Analysis (Taherdoost & Brard, 2019). These approaches are developed by considering qualitative (subjective) and quantitative (objective) selection criteria (Kumar et al., 2019), example, among other emerging variable, the costs (Modrak & Bednar, 2016), new technologies, changes in consumer regulations and preferences, focus on sustainability (Wetzstein et al., 2016), conflicting criteria (Aysegul Tas, 2012), and overall product quality and price (Gencer & Gürpinar, 2007). However, these ones in an agricultural context, are not common, due to the complex nature of agricultural production as a function of the farmer's supply capacity. In this context, it is most useful to apply approaches and techniques that reduce this complexity and that consider qualitative and quantitative variables in problems of selection of suppliers with multiple criteria structured as a decision problem (De Almeida et al., 2015).

One of the methods that incorporates these conflicting criteria for categorization purposes is the analytic hierarchy process (AHP) (Rajesh & Malliga, 2013) that has attracted the interest of many researchers mainly due to the mathematical properties (Rajesh & Malliga, 2013; Wolnowska & Konicki, 2019). This method is more favorable owing to its simplicity, ease of use, consistency, and overall flexibility in the decision-making process (Ho et al., 2010; Mani et al., 2014; De Carvalho Ressiguier Ribeiro & Da Silva Alves, 2016). On the other hand, System Dynamics (SD) has as its purpose to understand the structural causes that influence the behavior of the system (Asiedu & Ameyaw, 2020), and to study the behavior of a complex system and variables which are interrelated to influence growth and stability of the systems (Anh Nguyen & Le VO., 2019). This process is supported by a causal diagram, which describes the elements that make up the system (Iannone et al., 2015), resulting from its dynamic complexity or the number of elements involved in the system (Schwaninger & Groesser, 2020).

Although, in general, supplier selection approaches tend to be diverse in traditional industry (Schramm et al., 2020), in agricultural chains this is not common and a breach of criteria for belonging to the competitive advantages of suppliers can be found in the agricultural chain, above all, related to your orchard. For the problem of supplying fresh fruit in packaging / exporting companies, this article offers a decision support approach to select agricultural suppliers of fresh fruit supported by the SD. We employed the AHP along with System Dynamics for the selection of suppliers of Persian lemon to Mónica Lemon Exporting Company.

The AHP method helped determine the degree of importance of the supplier. Meanwhile, System Dynamics was used to model the interrelationships of elements of the agricultural system taking into account the supply capacity and quality of fruit supplied by the agricultural producer, and the speed of response in relation to the fruit requirement requested by the company. In order to achieve this, this article describes in the second section the context of System Dynamics in the supply chain of fresh fruit (FSC). In the third section the methodology that integrates the AHP and the SD is described. The results and discussions are presented in the fourth section, last but not least, a Conclusions section highlights the importance of this approach to select agricultural suppliers in the FSC.

2. System Dynamics in the supply chain of fresh fruit

Complexity is independent of the size, the number of parts, and the difficulty of the mission of the system, but depends on the variety and the intensity of the mutual interactions (Sellitto et al., 2019). In this way, a system can be considered complex not because of the quantity of its elements, but because of the interactions caused by its elements over time.

The scope of the SD has been extended to industrial and socioeconomic systems, and has found important applications in environmental systems (J. Liu et al., 2020), energy systems, transport systems, administration of production, and with special attention in the simulation of supply chains (Olivares-Aguila & ElMaraghy, 2021). In this last field, (Andres et al., 2016) and propose the evaluation of suppliers in a supply chain through SD, and highlight the complexity of selecting suppliers when several qualifying criteria are immersed to a supplier in said decision process, with financial and operational impact of a supply chain.

Although the selection of suppliers has been a topic sufficiently addressed in the manufacturing and services industry, the jobs reported of supplier selection in the agricultural sector, and specifically in agri-food chains, they have been scarce and have gained interest from academics, especially, with a sustainable approach (Amiri et al., 2021), taking advantage of Artificial Intelligence techniques, as can be seen in (Banaeian et al., 2018; Pang et al., 2017). In both studies, the use of fuzzy logic to model environmental criteria is highlighted, these criteria contribute to an inventory in the field of selection of agricultural suppliers. However, we still find a land that is not well served for this purpose and that requires to integrate tools that help to consider qualitative and quantitative criteria in a study as recommend (Y. Liu et al., 2019). So too, these studies generally have the main objective of by chaining two economic agents to synchronize between the supply and demand of an agro-industrial company throughout the supply chain. The complexity of this agricultural system is greater compared to goods supply chains, among other factors, due to the non-linear behavior of agricultural production and the presence of parameters (uncertain events) that influence the production system (Covas Varela et al., 2017).

As shown in Figure 1, the context of supplying fresh fruit begins with the demand for fresh fruit. Consequently, the company searches different sources of supply to meet its fruit needs. However, the uncertain nature of fruit production in orchards causes fruit volumes to be gathered higher than those required by customers. This buying strategy - currently used by fresh fruit packers, especially for export - generates inventories of fruit in storage, which, although it can be placed in subsequent orders in the market, this fruit has the disadvantage of shorter shelf life. This sourcing problem raises two research questions: which supplier can provide the fruit that is required? And what can the company commit to its customers if they don't know the quality and volume of fruit that an agricultural supplier can deliver?.

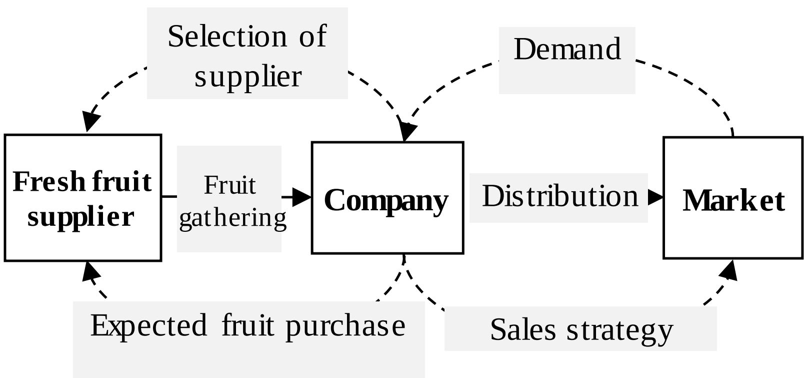


Figure 1. Context of supplying the agri-food supply chain.

To address this problem, this article is based on the methodology of the SD proposed by Forrester (1958) to simulate the agri-food supply chain and model 15-year supply scenarios (2003 to 2018) of historical records of supply of Persian Lima, of high season and low season of production in orchard, of packers of Persian Lima in fresh fruit in Mexico. This Approach to the Selection of Agricultural Suppliers is based on the following hypothesis: “The simulation of fresh fruit supply scenarios based on historical supply records provides information to improve the decision in the selection of fruit suppliers”.

3. Method

System dynamics (SD) is a methodology that helps build models of complex verbal systems in mathematical models, which allows to go beyond the studies of descriptive forms of a system. The SD is not restricted to linear systems, and supported by the computer, non-linear systems can be simulated without major complications, as are the processes immersed in the agri-food supply chain. The objective of this article is to present a decision support approach for decision-making, thus facilitating the selection and evaluation of agricultural suppliers in fresh fruit packing companies. The supplier evaluation and selection engine is are built in SD to simulate fresh fruit supply scenarios based on specific quality criteria for fresh fruit. With the result of the simulation of supply scenarios, the person in charge of buying fruit can improve his decision to select the agricultural supplier and his priority of entering the company to meet his needs for packing fresh fruit. The criteria of selection and evaluation of the agricultural supplier are: fruit supply capacity, the quality of the fruit delivered by the supplier, and the speed of response of the supplier to meet the need for fruit. These criteria are qualified by a panel of experts using the AHP to hierarchizes agricultural suppliers, assigning a value of importance with the level of fruit with export quality that the agricultural supplier delivers to the company in each lot of fruit supplied. As shown in Figure 2, the selection of suppliers is limited to suppliers with a historical record of fruit delivery to the company, which keep memory of the volume and quality of fruit delivered in past supplies. The suppliers have been classified as local suppliers, suppliers of the region and suppliers of another Federal Entity which are called foreign suppliers. The historical supply based on 16-year (2003 to 2018) of Persian Lima and the hierarchy value of AHP is fed to the SD Model (SDM) The SDM qualifies the best suppliers as a level of collaboration and reliability to meet a fruit requirement, both in high season or low production season of the fruit.

The SD methodology, described in Figure 2, is developed in 4 stages: 1) Structure of the current problem, 2) The main objective, 3) The simulation model taking into account the causal diagram and the Forrester model, and 4) Results. The construction of the Causal Model and Forrester Model, as well as the definition of the supplier selection criteria is analyzed with the panel of experts from Persian Lima defined in this case study.

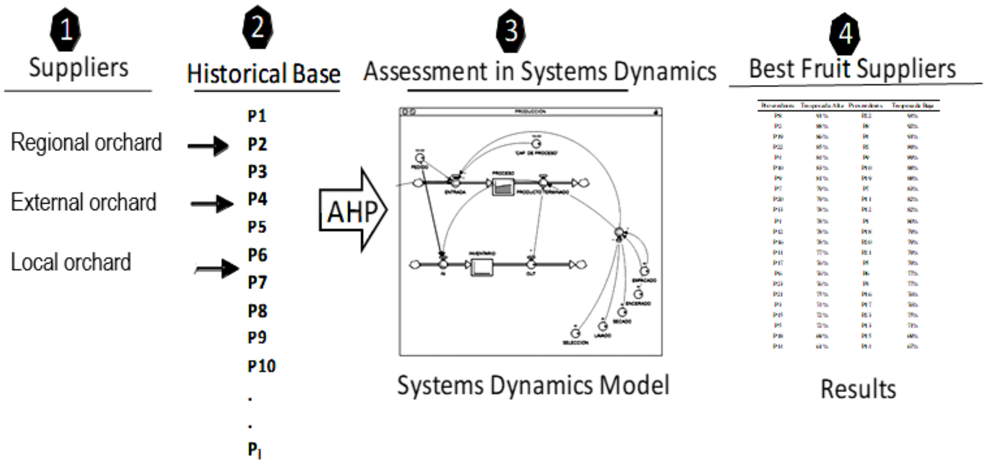


Figure 2. SD-based FSC vendor selection approach.

The study parameters that build the Systems Dynamics Model SDM are: the processing speed time (reception, sorting and packing of fruit), the capacity of the packing process (manufacturing capacity), and the inventory of fruit in fresh storage. Based on the market's fruit requirement (demand), the SDM helps identify the best supplier or group of agricultural suppliers to meet the customer's request. The system simulates the packaging process of Persian Lima from the arrival of the suppliers (arrival of fruit) to the packing of the fruit, and determines the way in which suppliers get into production.

4. Results and Discussions

Case study: Limones Mónica Exporting Company

The case of selecting agricultural suppliers to gather 100t of Persian lime in fresh fruit for quality packaging Europe, Japan and the United States have been studied. The methodology described in Figure 2 is adapted to this study in the following stages:

1. The agricultural suppliers that meet the fruit requirement, and also have a record of historical data on the cultivation of the fruit are identified.
2. The database is built, and the suppliers are ranked according to the quality of fruit supply demonstrated by the agricultural suppliers.
3. The SDM is Built, according to the characteristics of the fruit packing process, and the event simulated, to determine the sequence of entry of agricultural suppliers to the packing process.
4. The SDM describes the supplier's entry sequence to the fruit packing process, and provides information on the working hours required to comply with the production program, as well as the fruit inventory generated.

4.1 Objective of the simulation

Evaluate, select and determine the order of entry of the agricultural supplier that will supply the volume and quality of fruit, to cover the fruit requirement requested by the customer of the exporting company.

4.2 Construction of the model

The SDM model supported in a causal diagram that describes the relationships between variables that form the process of buying, selecting and packing fruit. The Forrester model is integrated by the causal diagram, the purchasing decision system and the fruit packaging system.

4.2.1 Causal diagram

The construction of the Causal Diagram considers the variables oriented to the final product from which one wants to obtain, these are: (1) the market demand according to the characteristics of the fruit that the client requests; (2) The production capacity, (3) The inventory of fruit related to the need of the customer's order; (4) The Supply Decision based on its quality, volume and speed of response. Figure 3 describes the relationship of the "positive or negative" feedback cycles between the study variables involved in the packaging process of the Persian Lima.

4.2.2 Forrester model
The Forrester Model described in Figure 4 is designed in two subsystems. The first describes the supply decision scenario based on the quality of the fruit and volume of supply of agricultural supplier. Once the supplier is selected, the second scenario described in Figure 4 describes the process of packing fruit.

Based on the client's requirement, the integration of these two subsystems simulates the order of entry of the suppliers, the process of receiving fruit and the operations of selection, washing, drying, waxing and packing of fruit. These processes are regulated by the demand for fruit requested by the customer.

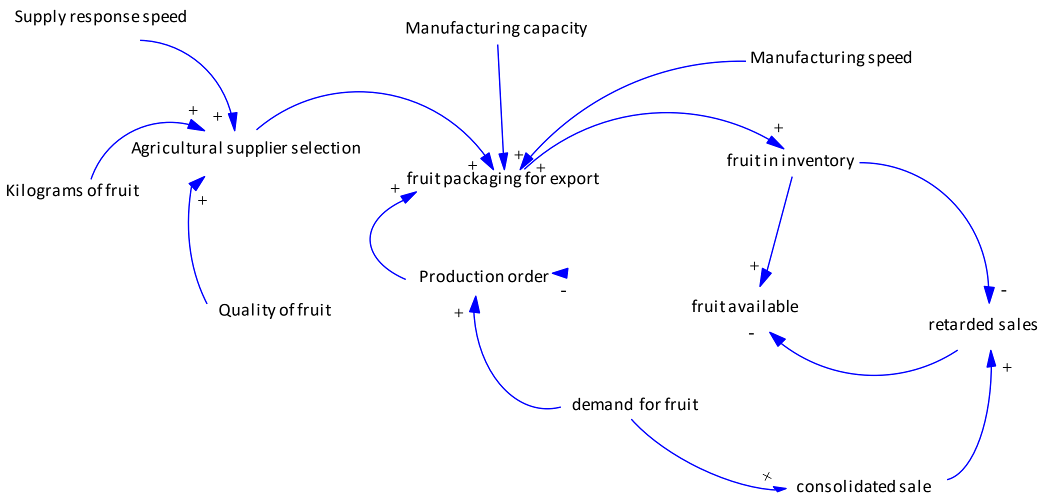


Figure 3. Causal relationship of the fruit supply system and fresh export fruit packaging.
Source: Stella Architect Trial ® Registration number: 2098197511.

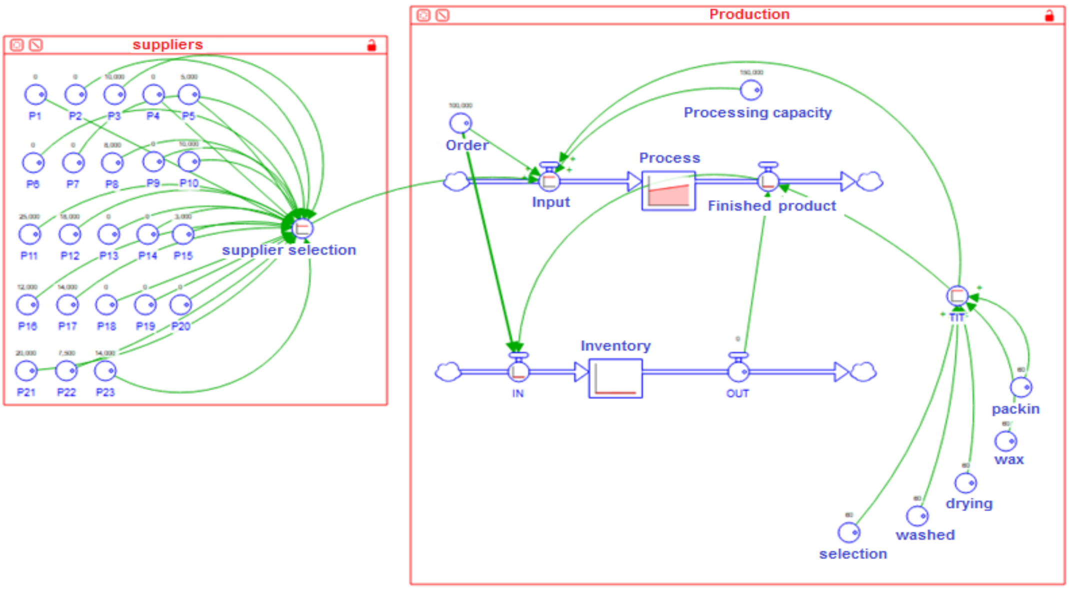


Figure 4. General System of supply and packing of fresh fruit.
Source: Stella Architect Trial® Reg. No. 2098197511.

4.3 Calculation memory

The training of suppliers based on technical assistance and work alliance in a win-win scheme, has been a strategy to ensure the supply of fruit from the agricultural supplier in the Limones Mónica Exporting Company.On this matter, Table 1 describes that 8 agricultural producers maintain the historical dynamics of supplying fruit to the company, both in the high season and in the low season of fruit production in the orchard. The percentage expressed in this Table 1, should not be understood as the percentage that covers the demand for the fruit required by the exporting company, but corresponds to the level of participation when the supply is required. On this matter, the P8, P2, P19, P22, P4, P10, P9, and P7 have more frequently met the need for high season fruit between 78 and 91%; while, in low season between 82 to 94%. Note in Table 1 that these suppliers ─ P8, P2, P19, P22, P4, P10, P9, and P7─ keep the level of collaboration in the process of supplying fruit to the company between seasons, to a greater or lesser extent, changing its role of importance between these seasons. For example, P22 in high season contributes fruit 85% of the time (8 to 9 times) that fruit is required, while in low season 94% (9 to 10 times that fruit is requested).

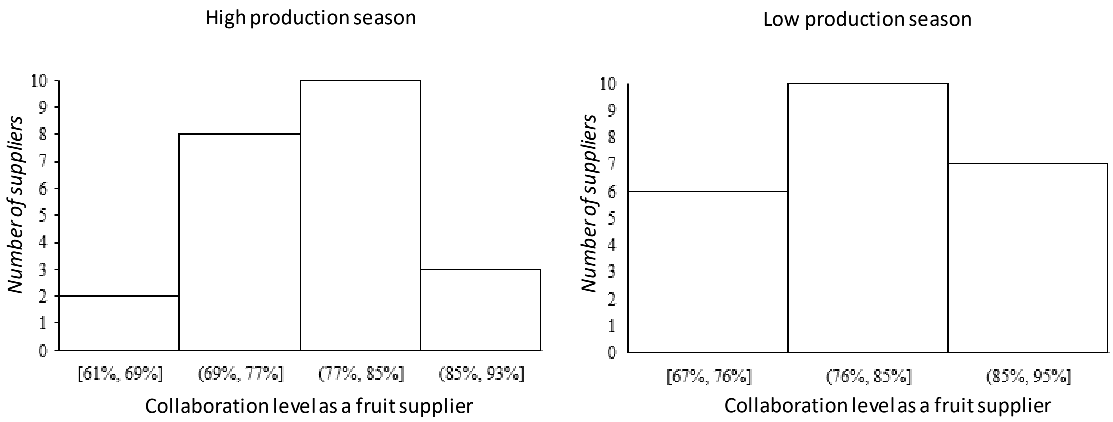
Also, Figure 5a and 5b shows that the Limones Mónica Exporting Company, maintains in its portfolio of suppliers of Persian Lima to 10 agricultural producers who have covered in both seasons of production, between 76 and 85% of their demand for fruit. However, given the uncertain and non-linear nature of agricultural field production between the volume of fruit harvest and the quality of the fruit, the company solves this problem by collecting the largest volume of fruit to concentrate the caliber / quality of fruit requested for the client. In this context and to answer the research question, which supplier can provide the fruit that the company requires? The panel of experts formed for this study uses the AHP method with the study parameters that build the SDM and the historical base of high and low season fruit supply. The AHP helped organize suppliers in a hierarchical structure based on historical records of the company according to the quality of fruit in each lot delivered to the company.

Table 1. Level of historical collaboration in the supply of Persian Lima†.

High production season		Low production season	
Agricultural suppliers	Historical collaboration	Agricultural suppliers	Historical collaboration
P8	91%	P22	94%
P2	88%	P8	92%
P19	86%	P4	91%
P22	85%	P2	89%
P4	84%	P9	89%
P10	83%	P10	88%
P9	81%	P19	88%
P7	79%	P7	83%
P20	79%	P11	82%
P13	78%	P12	82%
P1	78%	P1	80%
P12	78%	P18	79%
P16	78%	P20	79%
P11	77%	P21	79%
P17	76%	P5	79%
P6	76%	P6	77%
P23	76%	P3	77%
P21	75%	P16	76%

P3	74%	P17	76%
P15	72%	P23	75%
P5	72%	P13	71%
P18	69%	P15	69%
P14	61%	P14	67%

† 2003-2018 company data, analyzed in Stella Architect Trial® Reg. No.: 2098197511.



A. High production season. B. Low production season.

Figure 5. Strata of the level of historical collaboration in the supply of Persian Lima.
† 2003-2018 company data, analyzed in Stella Architect Trial® Reg. No.: 2098197511.

Table 2, hierarchically describes the proportion of fruit quality by caliber and the general proportion, of a portfolio of 23 agricultural suppliers. For example: In high season, supplier 5 has a quality of supply of 41.33% of export fruit, where, for each batch of fresh fruit delivered to the company, 6.97% is expected to be with quality of caliber 110 fruit; 6.96% caliber 150; 6.89% caliber 175; 6.71% caliber 200; 7.09% caliber 230 and 6.71% caliber 250. The difference of 58.7% is not fruit for export. This is explained successively for the rest of the suppliers.

Table 2. Quality of supply of Persian lime in high season and low season.

Supplier	Proportion by fruit size (caliber) in High Season						Total proportion	Supplier	Proportion by fruit size (caliber) in Low Season						Total proportioin
	110	150	175	200	230	250			110	150	175	200	230	250	
1	0.0886	0.0917	0.0794	0.0727	0.0909	0.0914	**0.5147**	1	0.0859	0.1013	0.0823	0.0888	0.0866	0.0912	**0.5361**
2	0.0865	0.0810	0.0837	0.0901	0.0774	0.0657	**0.4844**	2	0.0719	0.0795	0.0826	0.0750	0.0852	0.0815	**0.4757**
3	0.0790	0.0776	0.0762	0.0756	0.0696	0.0746	**0.4526**	3	0.0715	0.0750	0.0760	0.0706	0.0775	0.0748	**0.4454**
4	0.0701	0.0676	0.0689	0.0694	0.0712	0.0675	**0.4147**	4	0.0693	0.0624	0.0674	0.0690	0.0695	0.0673	**0.4049**
5	0.0697	0.0696	0.0689	0.0671	0.0709	0.0671	**0.4133**	5	0.0669	0.0640	0.0679	0.0677	0.0680	0.0697	**0.4042**
6	0.0610	0.0577	0.0591	0.0656	0.0595	0.0601	**0.3630**	6	0.0584	0.0619	0.0603	0.0579	0.0598	0.0589	**0.3572**
7	0.0533	0.0537	0.0543	0.0530	0.0546	0.0537	**0.3226**	7	0.0530	0.0534	0.0533	0.0525	0.0532	0.0535	**0.3189**
8	0.0473	0.0453	0.0475	0.0442	0.0478	0.0451	**0.2772**	8	0.0441	0.0453	0.0443	0.0463	0.0463	0.0464	**0.2727**
9	0.0461	0.0475	0.0459	0.0436	0.0454	0.0565	**0.2850**	9	0.0474	0.0463	0.0450	0.0455	0.0442	0.0461	**0.2745**
10	0.0449	0.0457	0.0454	0.0443	0.0446	0.0432	**0.2681**	10	0.0490	0.0440	0.0417	0.0451	0.0444	0.0445	**0.2687**
11	0.0343	0.0361	0.0477	0.0367	0.0350	0.0346	**0.2244**	11	0.0368	0.0354	0.0366	0.0344	0.0332	0.0351	**0.2115**
12	0.0351	0.0378	0.0375	0.0381	0.0357	0.0451	**0.2293**	12	0.0386	0.0370	0.0338	0.0361	0.0348	0.0341	**0.2144**
13	0.0298	0.0310	0.0318	0.0327	0.0312	0.0311	**0.1876**	13	0.0301	0.0302	0.0307	0.0302	0.0289	0.0302	**0.1803**
14	0.0284	0.0289	0.0283	0.0301	0.0298	0.0289	**0.1744**	14	0.0299	0.0290	0.0292	0.0285	0.0289	0.0285	**0.1740**
15	0.0276	0.0284	0.0281	0.0292	0.0280	0.0275	**0.1688**	15	0.0283	0.0279	0.0289	0.0277	0.0282	0.0267	**0.1677**

16	0.0259	0.0260	0.0251	0.0269	0.0271	0.0252	**0.1562**	16	0.0275	0.0262	0.0263	0.0247	0.0247	0.0265	**0.1559**
17	0.0211	0.0219	0.0216	0.0222	0.0224	0.0217	**0.1309**	17	0.0231	0.0214	0.0227	0.0211	0.0203	0.0198	**0.1284**
18	0.0230	0.0223	0.0230	0.0284	0.0239	0.0232	**0.1438**	18	0.0256	0.0235	0.0246	0.0245	0.0233	0.0250	**0.1465**
19	0.0208	0.0206	0.0235	0.0214	0.0228	0.0208	**0.1299**	19	0.0214	0.0212	0.0226	0.0230	0.0211	0.0223	**0.1316**
20	0.0184	0.0195	0.0200	0.0190	0.0194	0.0184	**0.1147**	20	0.0183	0.0189	0.0198	0.0201	0.0186	0.0193	**0.1150**
21	0.0167	0.0167	0.0163	0.0170	0.0169	0.0171	**0.1007**	21	0.0176	0.0198	0.0171	0.0212	0.0170	0.0193	**0.1120**
22	0.0157	0.0163	0.0155	0.0163	0.0160	0.0160	**0.0958**	22	0.0167	0.0159	0.0168	0.0173	0.0164	0.0165	**0.0996**
23	0.0114	0.0108	0.0101	0.0102	0.0128	0.0119	**0.0672**	23	0.0127	0.0116	0.0118	0.0143	0.0134	0.0118	**0.0756**

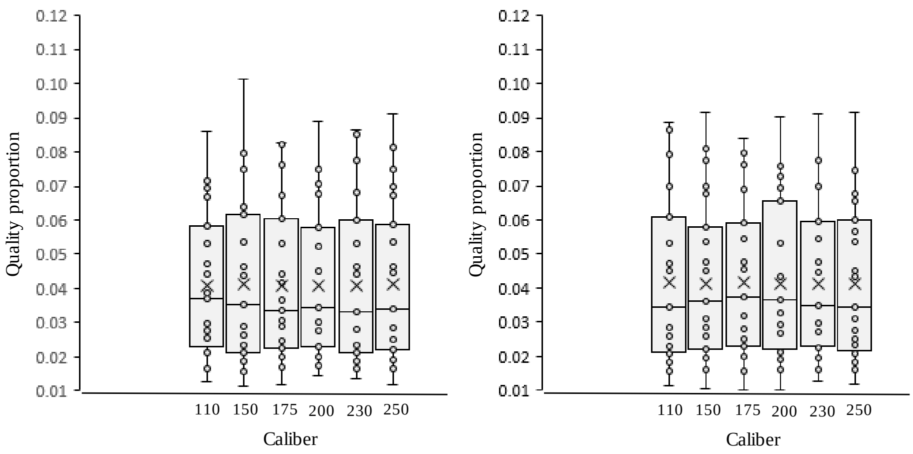
Source: Company historical base 2003-2018 and study analysis based on AHP.

The proportions of quality between calibers delivered by 23 suppliers in both, high and low season, bear a similarity with standard deviation of 0.0224 and 0.0220, respectively. In this sense, a test for the difference of means with maximum variance at 1-α of 0.05, demonstrates that there is no statistical difference of a supplier's supply between the two seasons. That is, the quality of supply of the lot is consistent, so it can be expected that the proportion of the quality of fruit delivered by the supplier will remain similar between harvest seasons, as long as the plantation conditions and agricultural practices involved prevail on stage under study. On this matter, (Fernández et al., 2015), the farmer must consider the importance of carrying out agricultural practices in his orchard. Therefore, Table 3 shows that among the 23 agricultural suppliers it is possible to maintain a consistency in the proportions for each caliber of fruit, as well as in its minimum and maximum expected. It can also be observed in this Table 3 and Figures 6 (6.a and 6.b), that a greater dispersion in the quality ratio in the 150 gauge in the High Season can be expected, and greater dispersion in the quality ratio in the 150 gauge, 200, 230 and 250 in Low Season. This information generated in the SDM from the historical base of high-season and low-season fruit supply, helps the company's fruit buying decision maker, to identify its best suppliers based on the fruit required to enter it into the process of packing.

Table 3. Proportion of average fruit quality and dispersion, high and low season.

Statistical	Quality proportion of fruit by caliber					
	110	150	175	200	230	250
Median	0.0356	0.0358	0.0357	0.0356	0.0341	0.0344
Minimum	0.0121	0.0112	0.011	0.0123	0.131	0.0119
Maximum	0.0873	0.0965	0.0832	0.0895	0.0888	0.0913
Average	0.0413	0.0414	0.0413	0.0412	0.0412	0.0412

Source: From Table2 data.



A. High season B. Low Season

Figure 6. Distribution of the quality of historically supplied Persian Lima.

4.4 Mathematical modeling

The mathematical model expressing the evaluation and selection of suppliers is explained in the following manner according to the following terms and definitions:

D_i, refers to the tons of fruit that are required by the market in period i,

P_i, refers to the order of tons of fruit to be made in period i, depending on the programmed production capacity of the fruit packing line in period i,

$PROV_i$ are the tons of fruit delivered by the supplier I,

VF_i, is the volume of fruit in tons delivered by the suppliers I selected,

Th_i, are the hours defined in the working day,

CP_i, refers to the capacity of the process expressed in tons per hour,

I_i, refers to the inventory in period I,

EI_{i+n}, is the inventory generated in the period i + n,

SI_i, are tons of inventory fruit that are packed in a new order.

$$VF_i = D_i - I_i + \sum_i^n PROV_i \quad \textbf{Eq. 1}$$

$$P_i = \sum_i^n PROV_i \quad \textbf{Eq. 2}$$

$$P_i = \frac{CP_I}{1/Th_i} \quad \textbf{Eq. 3}$$

$$I_i = EI_{i+n} - SI_i \quad \textbf{Eq. 4}$$

$$Cp_i \leq 15 \quad \textbf{Eq. 5}$$

$$Th_i \leq 10 \quad \textbf{Eq. 6}$$

Eq. 1 states that the tons of fruit that will be requested from agricultural suppliers are the complement to the inventory of fresh fruit in the company's warehouse. Eq. 2 in relation to what the suppliers will deliver, which is a function of the production capacity and the time of the working day, as can be seen in Eq. 3. Eq. 4 describes that the level of inventory Ii is a function of the inventory generated by the fruit that enters the process and that is not packed (EI) and the inventory output of stored fruit (SI) and that was arranged for packing. Eq. 5 and Eq. 6 represent restrictions on packing capacity per hour of work, and hours of the workday.

4.5 Simulation: Supplying scenario

Figure 7 describes, under this approach, the method of replication and analysis for the selection of agricultural suppliers.

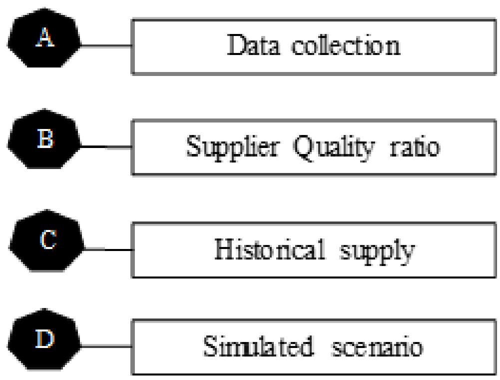


Figure 7. Methodology of replication and analysis for the selection of suppliers.

A. Data collection:

A historical supply scenario is simulated in low season of the year 2018, to gather 100t of Persian Lime in fresh fruit for export packaging (5 containers of export fruit of 20 t per container). The simulated system considers the following elements for a fruit classification line of 20 t/hour:

- There is no inventory of fruit in a fresh warehouse, nor in a cold store.
- 12 of 23 qualified suppliers in high season and low season.
- A historical supply described in Table 4.

Table 4 shows that historically 12 of 23 suppliers delivered the fruit to gather the 5 containers of fruit in the off season. In this Table 4, the supplier is described according to the sequence in which they entered the process, and the volume of fruit delivered to the company.

Table 4. Historical entry sequence of suppliers from Persian Lima to the packing process, in low season.

Agricultural supplier	Historical supply of Persian Lima in low season (kg)
P23	14000
P12	18000
P15	13000
P16	12000
P17	14000
P21	20000
P5	15000
P10	10000
P22	17500
P3	10000
P8	18000
P11	25000

Source: Historical record of kg of Persian Lima entered into the packing process in a packing lot in 2018.

B. Supplier Quality ratio:

The proportion of quality for each supplier is determined by the method of "percentage of composition" from the quality of supply described in Table 2. Then, Table 5 describes the quality proportion (QP) of the 12 historical suppliers described in Table 4. Table 5 is explained as follows: supplier 21, for each batch of fruit delivered, is expected to receive 15.71% with caliber 110, 17.68% of caliber 150, 15.27% of caliber 175, 18.93% 200 gauge, 15.18% 230 gauge and 17.23% 250 gauge.

Table 5. Historical proportion of fruit quality delivered by agricultural suppliers.

Agricultural supplier	Parameter	Quality proportion of fruit by caliber					
		110	150	175	200	230	250
P21	AHP	0.0176	0.0198	0.0171	0.0212	0.017	0.0193
	QP	0.1571	0.1768	0.1527	0.1893	0.1518	0.1723
P5	AHP	0.0669	0.0640	0.0679	0.0677	0.0680	0.0697
	QP	0.1655	0.1583	0.168	0.1675	0.1682	0.1724
P22	AHP	0.0167	0.0159	0.0168	0.0173	0.0164	0.0165
	QP	0.1677	0.1596	0.1687	0.1737	0.1647	0.1657
P17	AHP	0.0231	0.0214	0.0227	0.0211	0.0203	0.0198
	QP	0.1799	0.1667	0.1768	0.1643	0.1581	0.1542
P15	AHP	0.0283	0.0279	0.0289	0.0277	0.0282	0.0267
	QP	0.1688	0.1664	0.1723	0.1652	0.1682	0.1592
P8	AHP	0.0441	0.0453	0.0443	0.0463	0.0463	0.0464
	QP	0.1617	0.1661	0.1624	0.1698	0.1698	0.1702
P16	AHP	0.0275	0.0262	0.0263	0.0247	0.0247	0.0265
	QP	0.1764	0.1681	0.1687	0.1584	0.1584	0.1700
P3	AHP	0.0175	0.0750	0.0760	0.0706	0.0775	0.0748

	QP	0.0447	0.1916	0.1942	0.1804	0.1980	0.1911
P23	AHP	0.0127	0.0116	0.0118	0.0143	0.0134	0.0118
	QP	0.1680	0.1534	0.1561	0.1892	0.1772	0.1561
P10	AHP	0.0490	0.0440	0.0417	0.0451	0.0444	0.0445
	QP	0.1824	0.1638	0.1552	0.1678	0.1652	0.1656
P11	AHP	0.0368	0.0354	0.0366	0.0344	0.0332	0.0351
	QP	0.1740	0.1674	0.1730	0.1626	0.1570	0.1660
P12	AHP	0.0386	0.0370	0.0338	0.0361	0.0348	0.0341
	QP	0.1800	0.1726	0.1576	0.1684	0.1623	0.1590

Source: Estimates from Table 2.

C. Historical supply:

Table 6 records the historical data of fresh fruit supply described in Table 4. Note that supplier 23 was the first to enter fruit into the process. This supplier 23 entered ─according to Table 4─ 14000 kg, of which 10,500 kg of fruit were export quality, while 3,500 kg were of fruit inventory that did not meet export quality. This is explained successively for the remaining suppliers registered in this Table 6. It can also be observed in this Table 6, as well as in Figure 8, that the fruit entered with the 8th and 9th supplier was able to collect the 100 t of fruit required by the company. However, the company entered the fruit from 12 agricultural suppliers and accumulated 151902 kg of exportable fruit ─51902 kg more than required─ and a total inventory of 34598 kg of fruit that did not meet export quality.

While it is true that fruit with export quality manages to be placed in the export market in future shipments, it is also true the expenses involved in preserving the fruit in cold rooms and the consequence of loss of shelf life of the fruit until its Delivery to customers.

Table 6. Historical supply of export quality fruit to the packaging process.

Agricultural supplier	Fruit supplied (kg)	Kg of exportable fruit	Accumulated kg of exportable fruit	Generated fruit inventory (kg)	Accumulated fruit inventory (kg)
P23	14000	10500	10500	3500	3500
P12	18000	14760	25260	3240	6740
P15	13000	8970	34230	4030	10770
P16	12000	9120	43351	2880	13649
P17	14000	10640	53991	3360	17009
P21	20000	15800	69791	4200	21209
P5	15000	11850	81641	3150	24359
P10	10000	8800	90441	1200	25559
P22	17500	16450	106891	1050	26609
P3	10000	7700	114591	2300	28909
P8	18000	16560	131152	1440	30348
P11	25000	20750	151902	4250	34598

Source: From historical record of Table 4.

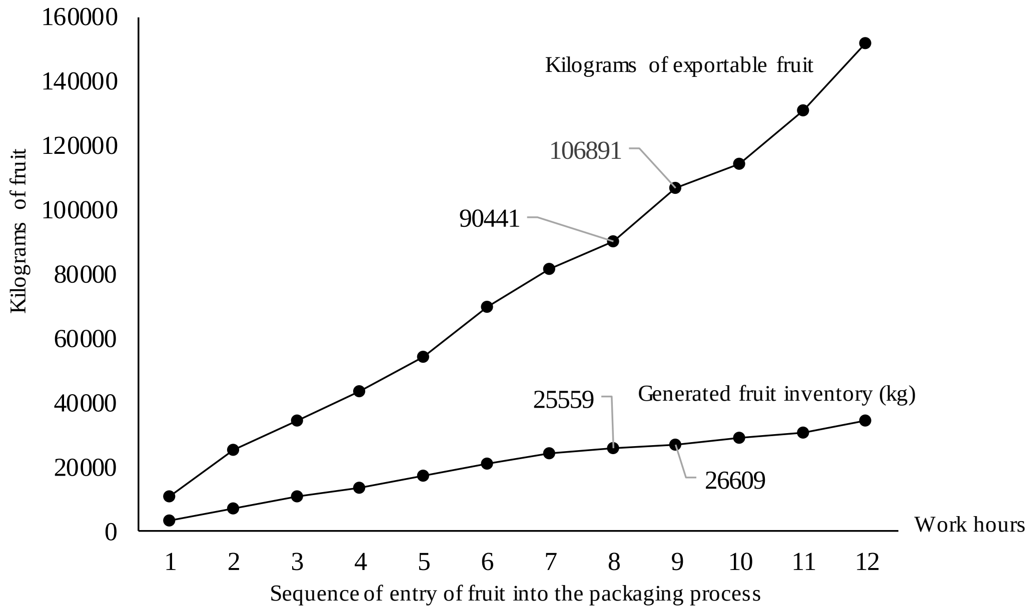


Figure 8. Supply of historical fruit and based on the quality of the supplier.
Source: From the historical record of Table 4.

D. Simulated scenario:
The information elements regarding the fruit packing capacity of the process, the volume of fruit requested by the company (100 t), the historically registered suppliers that delivered fruit to the company during the study period, as well as the value of the supply quality of each supplier described in Table 5. With this information, two scenarios are simulated. In the first, the SDM is manipulated describing the entry of fruit according to how it happened historically. In the second scenario, the 23 suppliers that the company has historically registered in high season and low season ─ described in Table 1 are fed to the SDM.

The SDM simulates the process of selection, washing, drying, waxing and packing of fruit, and recommends the order in which the agricultural suppliers must be entered "selected", with the following sequence: P1, P2, P21, P5, P22, P17, P15, P19, P9, P8, P14, P7, P16, P3, P23, P13, P20, P4, P10, P11, P12, P6 and P18. Based on this recommendation and based on the suppliers described in Table 4 that historically collected 100 t of fruit, the low season entry sequence is determined: P1, P2, P21, P5, P22, P17, P15, P19, P9, P8, P14, P7, P16, P3, P23, P13, P20, P4, P10, P11, P12, P6, P18.

The maximum supply capacity of these 12 selected agricultural suppliers is 162500 kg of fruit; volume greater than 100,000 kg required by the company.

According to Table 2, it is interesting to note that even if the P5 is registered with a higher proportion of fruit quality delivered in each batch, than the supplier P21, the SDM recommends that first P21 be entered and then P5, and So with other suppliers. This can be explained by the volume of fruit delivered by each supplier and by the capacity of the packing process of the company, in this way the SDM seeks to keep this process capacity used as established in Eq. 1. A schematic representation of the SDM is described in Figure 9.

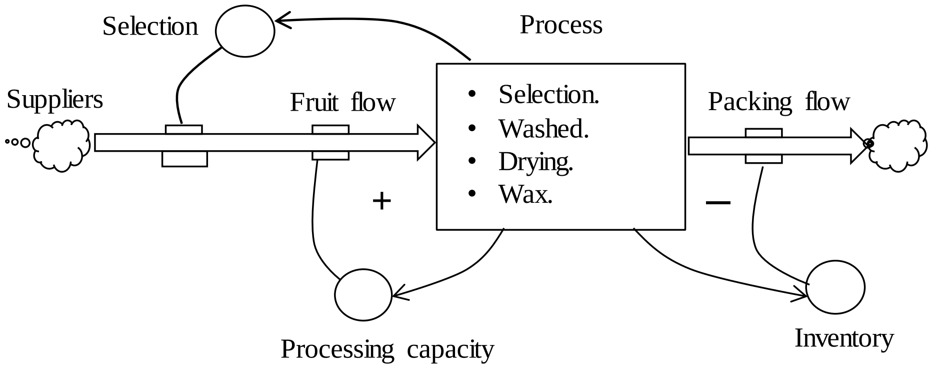


Figure 9. Selection of suppliers, process and packaging of Persian lime in SDM.

The sequence of historical fruit entry and simulated sequence of the simulated scenario in the SDM is described in Table 7. Table 7.1 describes the supply and sequence of historical entry of fruit to the packaging process of Persian Lima. It is seen that the SDM recommends the entry of fruit ─ vendor selection─ different from the order of historical entry. On the other hand, Table 7.2 records the simulation of the Persian Lima packaging process for an 8-hour work day. It is seen that, there is a proximity in the volume of fruit accumulated in both scenarios. However, at approximately 100 tons, a smaller inventory volume is distinguished by 5481 kg at 6 hours of operation in the simulated process (15724-10243 = 5481). This happens, when the provider is entered according to the program recommended by the SDM. The data in Table 7.2 are described in Figure 10 and the similarity in the classification process can be observed in both scenarios. The SDM simulates the classification of fruit based on the historical income with increases between working hours of 18425 kg, while based on the income recommended by the SDM, the increases are on average of 17396 kg. The classification of fruit entered in the historical form is explained in the form y = 18425x - 5739 with R^2 = 0.9985, while according to what the SDM recommends is y = 17396x - 3903 with R^2 = 0.9988. These values are similar for the information values that fed the SDM: Classification of 20 t/h, for a quota of 100 t.

Table 7. Simulation of the historical classification process and SDM.

Table 7.1 Supply of fruit.					Table 7.2 Classification of Fruit in SDM			
Historical fruit entry sequence		Simulated fruit entry sequence			Historical process Accumulated		Simulated process Accumulated	
Agricultural supplier	Kg	Agricultural supplier	Kg	Work hours	production	inventory	production	inventory
P23	14000	P21	20000	1	15619	1845	15426	1531
P12	18000	P5	15000	2	31858	3802	31279	3086
P15	13000	P22	17500	3	48715	6465	47557	4736
P16	12000	P17	14000	4	66192	9282	64262	6528
P17	14000	P15	13000	5	84288	12274	81393	8353
P21	20000	P8	18000	6	103003	15724	99650	10243
P5	15000	P16	12000	7	122337	19536	118033	12195
P10	10000	P3	10000	8	142290	23367	137442	14458
P22	17500	P23	14000	9	163152	27348	-----------	-----------
P3	10000	P10	10000	10	-----------	-----------	-----------	-----------
P8	18000	P11	25000	11	-----------	-----------	-----------	-----------
P11	25000	P12	18000	12	-----------	-----------	-----------	-----------

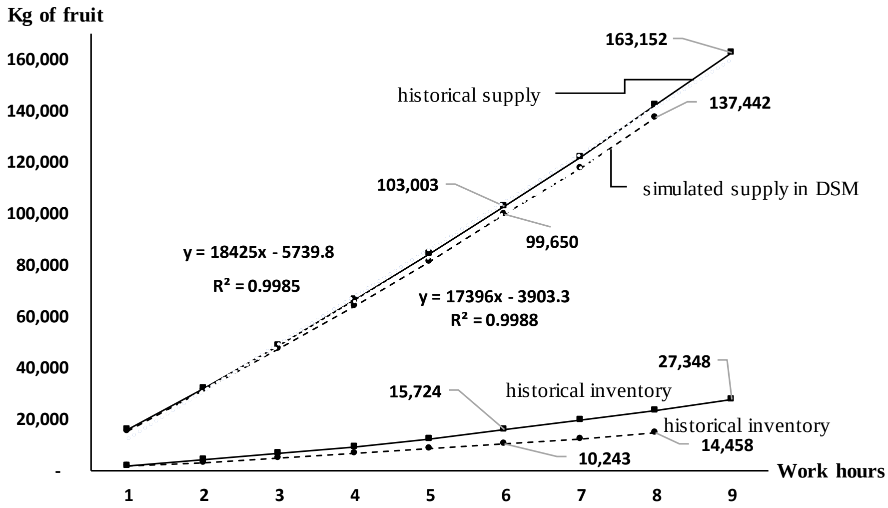


Figure 10. Volume of fruit classified in SDM Historical *vs* simulated.
Source: Historical and simulated scenario for supplying fruit in the SDM.

Table 8 describes the fruit size in kilograms expected by each supplier. Table 8 is explained as follows: Based on Table 4, supplier 21 is expected to deliver ─of 20,000 kg of fruit─ 15800 kg exportable fruit, of which 2483 kg is expected to be of 110 caliber; 2793 kg of 150 caliber; 2412 kg of 175 caliber; 2991 kg of 200 gauge; 2398 kg of caliber 230 and 2723 kg of caliber 250. Similarly, for the rest of the suppliers.

Table 8. Entry of Fruit "Expected" export route.

Simulated fruit supply	Fruit for export	Quality proportion of fruit by caliber					
		110	150	175	200	230	250
P21	15800	2483	2793	2412	2991	2398	2723
P5	11850	1961	1876	1991	1985	1994	2043
P22	16450	2758	2626	2775	2857	2709	2725
P17	10640	1914	1773	1881	1748	1682	1641
P15	8970	1514	1492	1546	1482	1508	1428
P8	16560	2678	2751	2690	2812	2812	2818
P16	9120	1609	1533	1539	1445	1445	1550
P3	7700	344	1475	1495	1389	1525	1472
P23	10500	1764	1611	1639	1986	1861	1639
P10	8800	1605	1441	1366	1477	1454	1457
P11	20750	3610	3473	3591	3375	3257	3444
P12	14760	2657	2547	2327	2485	2396	2348

Source: From Table 4 and Table 5.

The simulated process in the SDM based on the quality of supply shows the advantage of processing the volume of fruit, compared to the historical income of the fruit in low season of the year 2018 to cover the volume of required exportable fruit. In this way, and based on available to suppliers, the person responsible for buying fruit would have the opportunity to decide the number of agricultural suppliers that should enter the process of classification and packaging of fruit to fulfill the customer order and not enter more fruit than necessary. For example, in the historical income, 11,624 kg of fruit inventory could be avoided, while with the entry of suppliers suggested by the SDM in an 8-hour working day, only 4,215 kg of fruit inventory would be obtained. The value of this inventory in 2018 would be US $ 10,869 and US $ 3,942 respectively. In general, this approach to selecting agricultural suppliers, unlike

(Fernández et al., 2014), presents the alternative of deciding which supplier will provide the fruit and the supplier's entry sequence to the packaging process. In this sense, the person responsible for the purchase of fruit can rely on the SDM to decide hierarchically which vendor to request fruit.

5. Conclusions

The selection of suppliers is a complex and combinatorial process in which the decision criteria are usually in conflict. In this article, an approach to selecting agricultural suppliers through the AHP and System Dynamics has been presented to evaluate the quality of fresh fruit supply with criteria related to the response speed, supply capacity and quality of fruit supplied. The AHP method helped to rank the supply quality of the agricultural supplier, while an SDM helped to model supply scenarios based on the selection and order of entry of the supplier to the classification and packaging system. The simulated scenario through SDM has proven to be a useful decision support tool for supplier selection. The fruit buying decision maker can rely on this SDM to make the selective purchase of fruit from the supplier-orchard and decide the volume of fruit that will enter production. This decision has the advantage of reducing the inventory of fresh fruit not required for packaging, which, although it is fruit of exportable quality, the fruit storage reduces the shelf life of the fruit on the market. In this sense, the validation of this hypothesis warns the opportunity to negotiate the advance purchase of fruit, and establish sales strategies. The SDM has the limitation of having a historical record of suppliers, and the weakness of not predicting the volume of fruit according to the classification of exportable fruit. This weakness is resolved with the AHP method and the "percentage composition" method. In this sense, an interesting topic that can give continuity to this work is to use the information of the supplier's entry sequence to the packaging process to feed an artificial environment that classifies the fruit according to the quality calibers. Another interesting topic is to simulate the agricultural practices carried out by the farmer in the orchard, to support the decision to buy fresh fruit from the orchard and in order to predict what the orchard is capable of providing regarding the volume of fruit that can be collected and its fruit quality, as well as its quality of fruit, simulating chaining scenarios based on the uncertain demand of export markets.

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