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USING SYSTEM DYNAMICS AND FUZZY LOGIC TO ASSESS THE IMPLEMENTATION RFID TECHNOLOGY

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Abstract – The Technological growth has led to the acquisition and implementation of technologies to improve the performance of organizations that make up the supply chain. The paper presents a RFID Technology Implementation Model on picking operation under the approach system dynamics and fuzzy logic, to analyze behavior over time and information and material flow in the fruit supply chain assessed by means of technology change policies.

The results show that the model has a better performance by integrating fuzzy inference system and system dynamics simulation, allowing make decisions through policy implementation traceability technology in fruit supply chain on the lead-time picking operations. Whereas, an innovation approach that combines elements complexity-uncertainty, causality-experience, behavior-knowledge through of loop causal, dynamics simulation model and fuzzy inference system.

Key words: System Dynamics, Fuzzy Logic, Supply Chain, Technology Management and RFID Technology.

Introduction

The focus paper shows the impact on information and material flow in technology management activities of organizations that make up the supply chain. In this way, the traceability technology used in the supply chain improves the performance in control quality and setup time (*picking*) associated with the supply chain. Time spent picking operations in the storage products or raw materials represent a significant percentage the total cost. This in turn, affects the quality and food safety for consumers and organizations of fruit supply chain. However, the traceability technology implementation requires appropriate policies for technology management. The model simulation shows the behavior of policy implementation traceability technology on picking operations in fruit supply chain.

The behavior of the model under study is analyzed by means of a simulation model based on the principles of the system dynamics methodology and fuzzy inference system.

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Therefore, the results of the integrated model (System Dynamics-Fuzzy Inference System) were evaluated on performance measures of the flow behavior in the supply chain. This paper is organized as follows. Firstly, section presents the background of the model. Second, the methodology and simulation model structure. Third, simulation model integrated into the fuzzy logic system is presented. Finally the results and conclusions are provided.

Background

The globalization of markets has created a dynamics between organizations framed on competitiveness and productivity. The economic policies of globalization have enabled the integration of markets, so it is important to perform an analysis focused on identifying the competitive advantages in the fruit supply chain (Orjuela C., Calderon, & Buitrago, 2006). In Colombian, one of interest is the technological aspect due to market expansion and diversification effect on product manufacturing companies. This is evidenced by the use of various information technologies (Figure 1). These are highlighted using traceability techniques, technologies CRM (*Customer Relationship Management*) and DRP (*Distribution Requirements Planning*) and production software a 60 per cent. However, The technology using Colombia in manufacturing companies is related to MRP application (*Material Requirements Planning*), transactions specializing in EDI/XML, storage and distribution software.

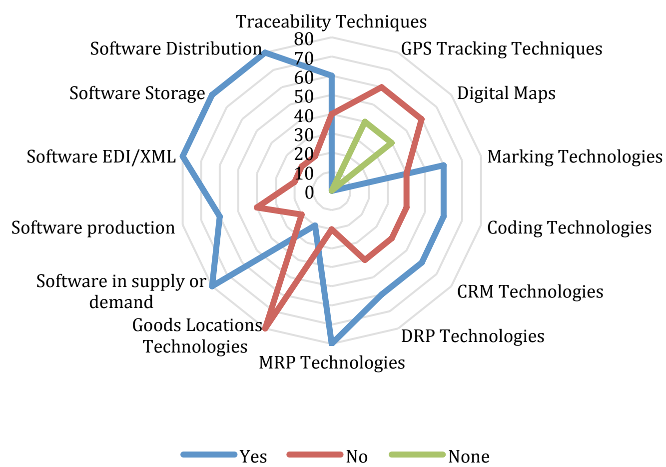

Figure 1. Technologies Information Used in Manufacturing (Colombia).

In this sense, the warehouse management system is an essential part of supply chain. The storage activities (receipt, picking and y distribution) are a fundamental in your design (Frazelle & Sojo, 2007). One of the biggest concerns of a warehouse management system is the picking activity. Therefore picking activities represent a higher cost in storage operations (Chen, Hwang, & Chen, 2009). The picking can be understood as the activity in which the enlistment of products and raw materials. It intended to respond to the request of customers in the shortest time.

Traceability is an essential process in picking activities of the warehouse. In this sense, applications of RFID on picking operations propose evaluate the performance of the designs and procedures performed in a warehouse (Chen, Hwang, & Chen, 2009). These uses improve picking operations and thus the internal traceability of manufacturing processes in the fruit supply chain.

According to, the Asociación Nacional de Empresarios de Colombia (2012) a 77,8% companies know the picking optimization systems, but these systems have not. Although the percentage of companies with picking optimization systems is low (22,2%) compared to those without, it is noteworthy that 12,7% have picking optimization systems through development internal organization, while 6,3% has been obtained by a supplier. It is observed in Figure 2 that 3,2% of surveyed companies have picking optimization system through ERP systems. This accounts for the need to design appropriate picking systems that support the manufacturing companies (Asociación Nacional de Empresarios de Colombia-ANDI, 2012).

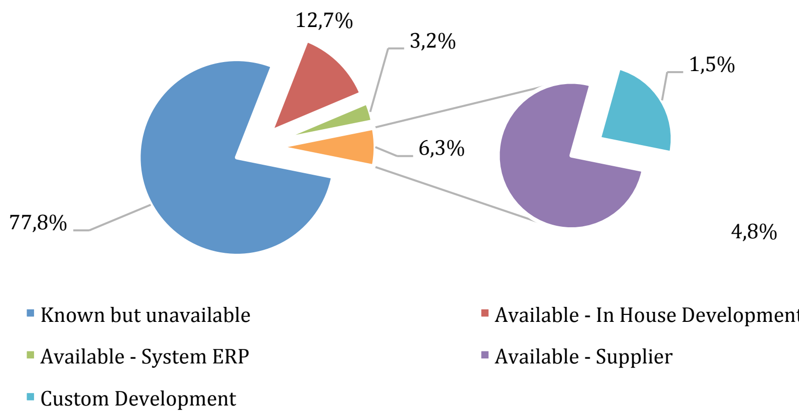

Figure 2. Picking optimization system.

Picking procedures are therefore related to different technologies. There are two ways to perform these procedures (*picking in situ and picking stations*). Studying picking operations from Colombia represent 80% of high-impact activities in logistics, therefore require a high level of training in the fruit supply chain (Puentes G., 2006). The different techniques, aspects and variables that must be considered the picking operations are relevant to determining the quality and food safety in fruit supply chain.

System Dynamics approach in planning technology

The technology implementation is an activity technology management and this from knowledge management. This approach from system dynamics is approached by Wolstenholme (2003) in the assessment of technology level under simulation the contribution is the analysis of structural behavior in the technology changes. Dharmaraj et al. (2006) proposes a model that represents the dynamics of technology in an innovative organization, the results focus on alternatives to obtain competitiveness of the organization. He analyzed two effects of loops, they relate to the change in technology and the adoption of new technologies. On the other hand, Karikoski et al. (2009) and Yin & Xia (2011) approach the effects of technology transfer and emerging technologies; the first focuses on the analysis under various scenarios of emerging technologies, while the other focuses on the study of integration between the system's strategic partners for transfer technology.

The relationship between integration and technology management and logistics system of the supply chain is approach to Kalenatic et al. (2009) using a methodology that has flows that relate both aspects and proposes the sub-systems that support the central system in organizations.

The implementation models of RFID technology studies to Chen (2011) and De Marco et al. (2012) proposed the implementation from the growing market for RFID technology and the effect on retail stock. In this way Herrera and Orjuela (2012) approach the implementing RFID technology that is developed in this paper. Analysis of these approaches is presented in Figure 3.

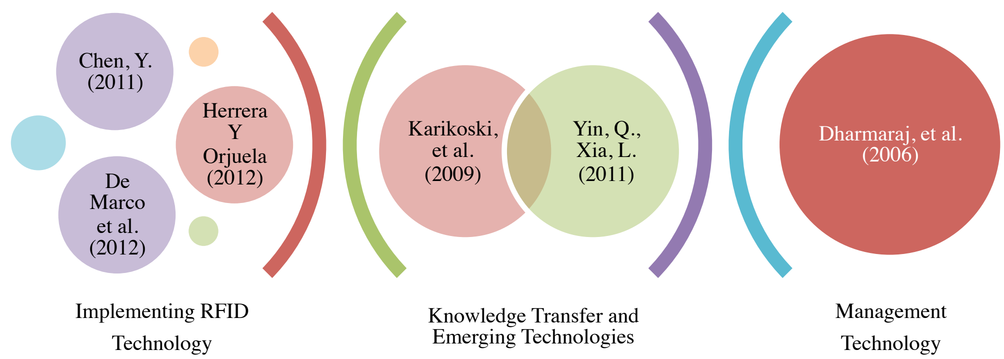

Figure 3. System Dynamics Approach in Implementing RFID Technology-Technology Management.

In conclusion, we have proposed systemic models and innovation policy development and implementation of food safety technologies that address the complexity of the system and the relationship between variables making it an appropriate methodology in dealing with the planning and implementation of technology and incidence or food product traceability in fruit supply chain.

Dynamics System and Fuzzy Inference System

The approach of integration between System Dynamics and the Fuzzy Inference Systems on the analysis of supply chain models is a novel approach that has allowed a better qualitative understanding of model (Guzmán & Andrade, 2009). Applications proposed by Ghazanfari et at. (s.f.) in which causal diagrams are developed with fuzzy relations. However, these applications take modified through fuzzy sets that are applied in supply chains, the first work developed by Zadeh (1965) and Zimmerman (1983) suggest the genesis of these methods.

The evolution of operations research models is evident in the development of comprehensive and dynamic model are essentially characterized by the combination of mathematical approaches that contribute to make decisions. Xu & Li (2011) using fuzzy optimization and dynamic systems, proposes a conceptual perspective and comprehensive dynamic model which is to approach five parameters: initial (C), flow (X), level (G), fuzzy (Z) and objective (F) of the system under study, these relate to the simulation of System Dynamics (SD) and programming objective Function (FMOP) through the initial parameters (C) to set comprehensive and dynamic model (SD-FMOP). Later, the fuzzy parameter optimization with genetic algorithms is performed, and finally performs a simulation on system dynamics.

On the other hand, Mutingi & Mbohwa (2012) made a proposal that includes four phases. The first phase developed a simulation model with system dynamics. In the second phase the system dynamics model used a fuzzy parameters, with which the uncertainty of the real situation was addressed. Subsequently, the mathematical model was solved with an optimization technique. Finally, The policies are designed through the obtained parameters.

The approach of using system dynamics and fuzzy logic is discussed since 1990. Mula, J. (2013), Campusano-Bolarin et al. (2013) and Peidro et al. (2010) discussed studies on the behavior of inventories in the supply chain. Furthermore, Carvalho (2000) presents studies about fuzzy cognitive maps and qualitative relation in simulation models under system dynamics.

The work done by Xu & Li (2011) and Ng et al. (2009) presented an integrated approach between bio-inspired techniques (genetic algorithmic) techniques of Fuzzy Optimization and Systems Dynamics applied in supply chain and workforce. The use of genetic algorithms as method of integrated solution with System Dynamic is proposed by Li & Wang (2010), Lian & Jia (2012) and Ng et al. (2009) in application of inventory system optimization. On the other hand, the studies discussed by Xu & Li (2011) and Li, Xu & Jiang (2013) used the Linear Multi-Objective Optimization method as integrated methodology of System Dynamics. Liu, S., Triantis, K.P., Sarangi, S. (2011), used the linguistic variables in a model sales and service showing the simulation results corresponding to the probability of generating new customers and profit taking considered fuzzy rules.

Applications of fuzzy optimization models in the areas inherent in production management and supply chain have taken hold and have been extended in order to make decisions taking into account the uncertainty of the real system. That is why the use of such models has been widely reported. Dejmek & Skoglund (2007) discuss the internal traceability introduces the term fuzzy traceability, demonstrating the difficulty in tracing the raw material used in a process in a factory line of liquid foods. Therefore, the fuzzy optimization and simulation approach in the integration of methods used to address problems of tracking or fuzzy traceability.

Other approach in integrated optimization model and simulation in the supply chain is addressed by Abo-Hamad & Arisha (2011). In this sense the Integral Dynamics Models of planning, scheduling and control approach by Kalenatic (2001) and Orjuela et al. (2010). The first is developed in manufacturing and the second is proposed in the service sector.

In conclusion, Fuzzy Inference Systems approach the parameter uncertainty in the real system. This is usually modeled with statistical tools, however in some cases when the number of variables is not significant other techniques that measure are used (Kalenatic, 2001). Therefore, in the next chapter developed the methodology of model.

Methodology

The methodology was developed two approaches. The first related to the simulation model continues of traceability technology implementation. The second supported under a fuzzy logic system that contributes to the simulation model under dynamic systems with the knowledge base. The integration favors the process of decision-making, because the complexity is approach with the System Dynamics and uncertainty in the parameters of simulation. The relationship between the methodologies is shown in Figure 4.

In a complex system involved actors and experts. The first characterized by complex relationships in which they are immersed and the experts who have the knowledge base of system. The integration methodology provides the actors in the case of simulation and causal diagram construction and the experts who contributed to the design of fuzzy system structure. In this sense, the decision rules of simulation model are related to the knowledge base on the designed fuzzy logic system.

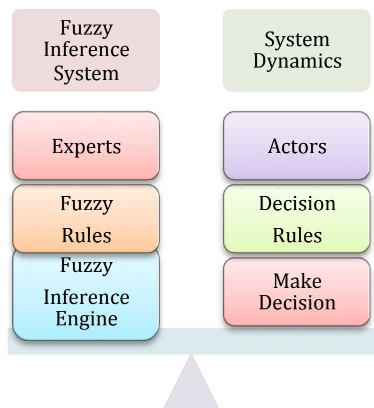

Figure 4. Relationship Integral and Dynamic Fuzzy Model

In the Figure 5 presents the methodology of integration between System Dynamics and Fuzzy Inference System. The relationship of integration in the simulation with fuzzy parameters where the simulated model is combined in order to analyze the behavior and decisions make.

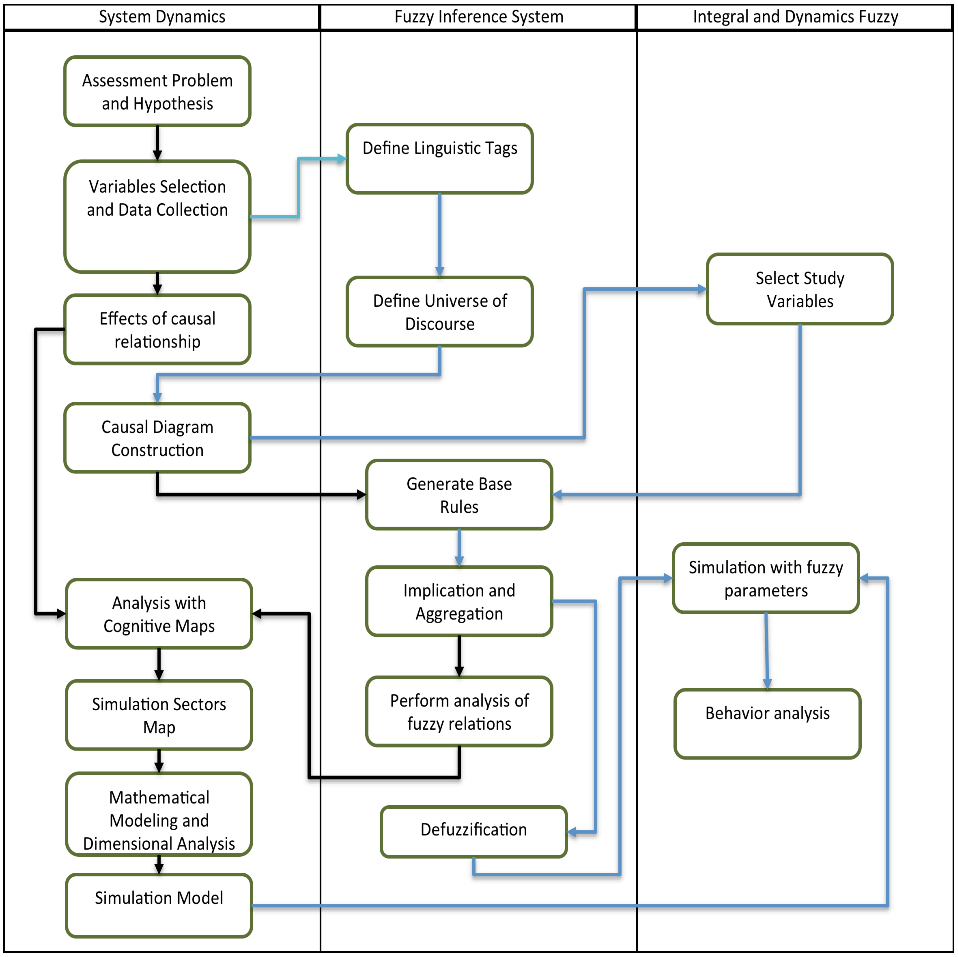

Figure 5. Methodology Integration - Integral and Dynamic Fuzzy Model

The design of the system behavior measures is presented in the following separate to analyze the traceability technology implementation according to flow information, materials and investment used in fruit supply chain.

Design System Performance Measures

The system performance measures were chosen based on simulation developed sectors. These measures are presented in Figure 6, it focused on information management and traceability system, due to the importance that this sector represents the dynamic hypothesis. The mathematical model of system developed is presented:

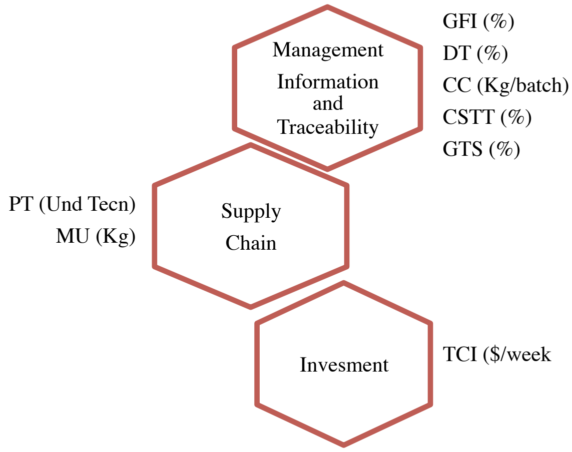

Figure 6. System Performance Measures.

Structure Model of System Dynamics

Assessment Problem

The growth organization requires a change in the procedures and processes at the impact of food safety and quality of fruit products. The expansion of markets and technological needs associated with product specifications requires investments that provide for the inclusion of technology. Therefore, the question asked which is addressed with the model is:

How should make the implementing traceability technology RFID in picking operations of the fruit supply chain?

Starting from this assessment problem is proposed the dynamics hypothesis of Integral and Dynamics Fuzzy Model.

Hypothesis

By developing a model that integrates system dynamics and fuzzy logic may determine management policies for implementing traceability technology in order to improve the setup time and traceability in fruit supply chain.

Causal Diagram Model

The causal diagram model for traceability technology implementation in fruit supply chain, proposed from the perspective of System Dynamics, addresses the conceptual elements of industry experts and several approaches and structures. Therefore, the causal diagram in the traceability technology implementation in fruit supply chain shown in Figure 7. It can be seen that the causal diagram proposes five main effects: Implementing Traceability Technology, Inventories of raw materials and quality, Flow production, storage and demand, human resources, Production capacity (infrastructure).

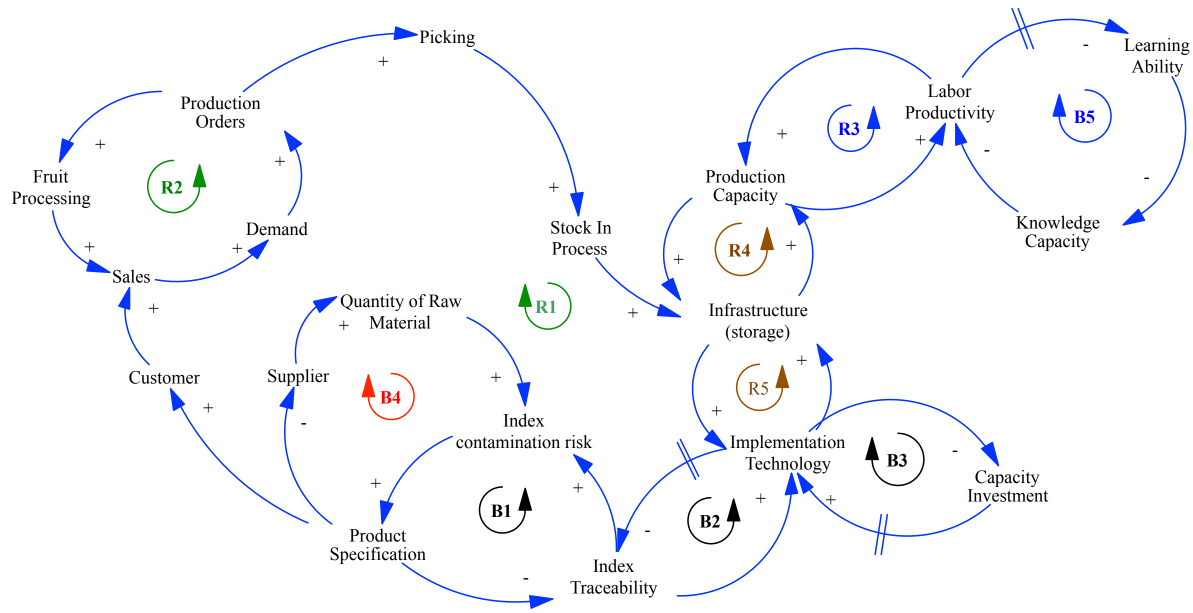

Figure 7. Causal Diagram - Integral and Dynamics Model.

In summary, the implementation traceability technology indicators improved traceability and product specifications, however this behavior is controlled by the system's capacity to invest in technology.

Simulation Sectors Map

The model sectors are designed taking into account flows: Information, Material, Capital, Money and Human Resources (Forrester, 1958). The structure of sectors map having different feedbacks and flows. The flows are identified by structure (See Figure 8):

a) Feedback Flow Supply Chain: includes the sectors of Raw Material Supply, Processing, and Consumer.
b) Feedback flow Traceability and Information: includes relations sectors of Information Management and Tracking System.
c) Feedback Flow Management Technology: provides relations sectors of Planning, Acquisition and Incorporation of Technology, Investment, Technology and Human Resources

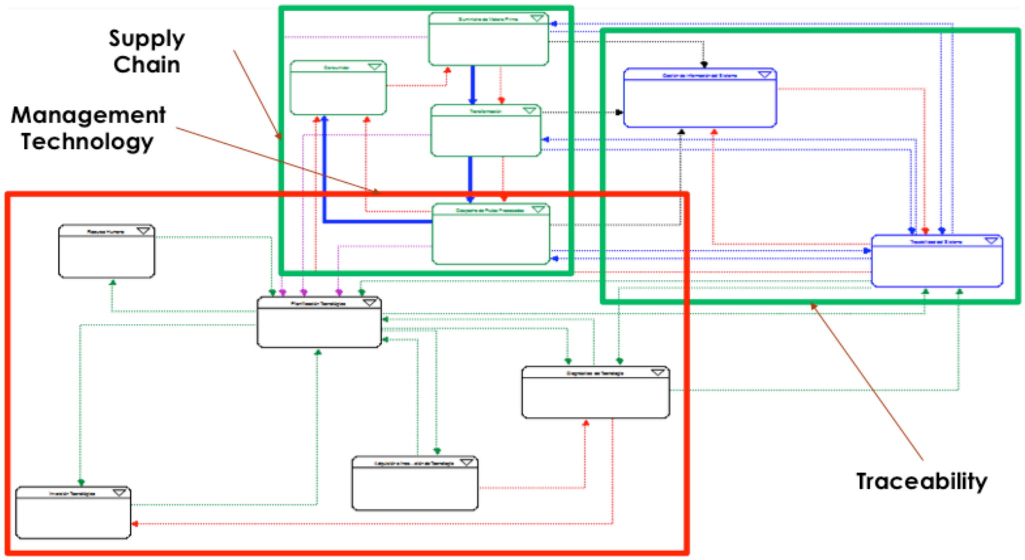

Figure 8. Structure Sector Map of Integral and Dynamics Model.

The intercept Technology Management shows the relationship this has with the supply chain and information (traceability and information management) concept that adds value to the structure simulation applied in this paper. Consequently, the Technology Management as the cornerstone of the model relates to the interface and integrates simulation, with the purpose of analyzing the behavior of the technology across different aspects (planning, acquisition and incorporation, investment, diagnosis and human resources).

Systematization of Simulation Model

The continuous simulation model was developed in three stages of modeling: Design interface (simulation sectors), Design Simulation Model and Control System Design. The first stage was analyzed in the previous section, in which the structure of model and simulation sectors is presented.

The second stage of modeling and build is the Simulation *Forrester Diagram* as shown in Figure 9. This is divided into three areas comprising the flow information, materials, human resources, capital (technology) and money. The area that relates the flow of material and information is called supply chain. This simulation includes four sectors (supply of raw materials, processing, shipping and consumer).

Traceability area show in the Figure 9 relates the flow area information and material supply chain. Also, this simulation covers two sectors (Information Management and Tracking System). Finally, the Technology Management that includes the key areas for the implementation and analysis technology in the system.

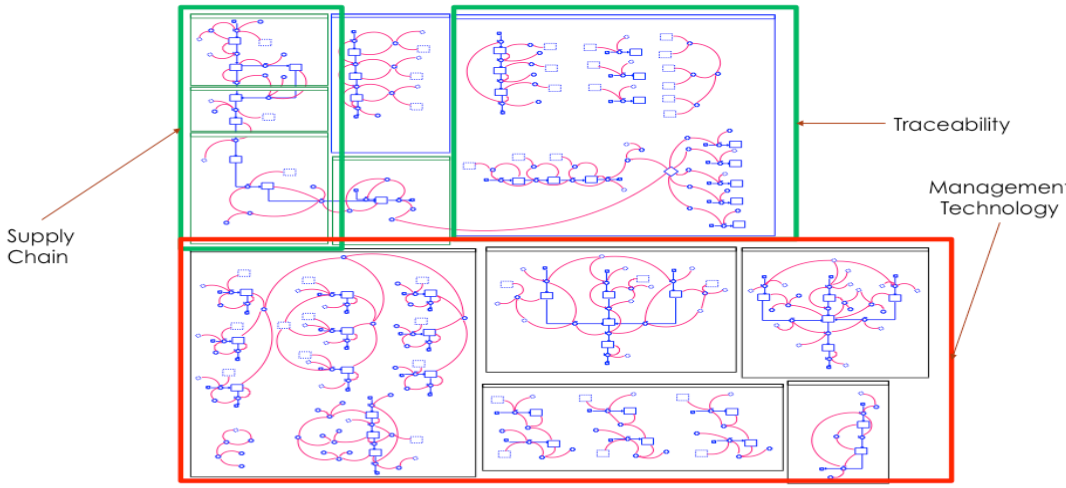

Figure 9. Forrester Diagram Simulation Model Fruit Supply Chain - Technology Management Traceability

The results of performance include implementing policies Traceability Technology, measures system performance and behavior of the graphs of information flows, human resources, equipment, technology and money.

Structure of Fuzzy Inference System

A Fuzzy Inference System was the ability to make a specific input value and through a fuzzy inference process based on rules, throw a crisp output value. The purpose of designing the Fuzzy Inference System model for implementing traceability technology is based on two aspects: analysis of the causal diagram structure and design values to improve policy technology management.

The type of Fuzzy Inference System is used *Mandani*. This system includes the following steps: fuzzification, application of fuzzy operators, implication, aggregation and defuzzification. Each applies to diagram causal variables and parameters associated with picking operations and quality (traceability). Next, the structure analysis of simulation model is shown.

Structure Analysis of Simulation Model

Design policies

The design policies of sector planning traceability technology are based on two algorithms that determine the area (sector) intervention technology and alternative technology. The first comprises the information flow, material flow and investment capacity. The algorithm in Figure 10 determines the area to intervene.

j: *Sector implementation of supply chain (supply, processing, shipping).*
k: *Subscript represents a type level k.*
CFIjk: *Level Information Flow capacity of sector j.*
CFMjk: *Level of Material Flow Capacity of sector j.*

VPNjk: *Net Present Value of Investment sector j.*
EFIjk: *Input Flow Information sector j.*
SFIjk: *Output Flow Information sector j.*
EFMjk: *Input Flow Material sector j.*
SFMjk: *Output Flow Material sector j.*
PFIj: *Policy Flow Information sector j.*
PFMj: *Policy Flow Information sector j.*
PFInvj: *Policy Investment sector j.*

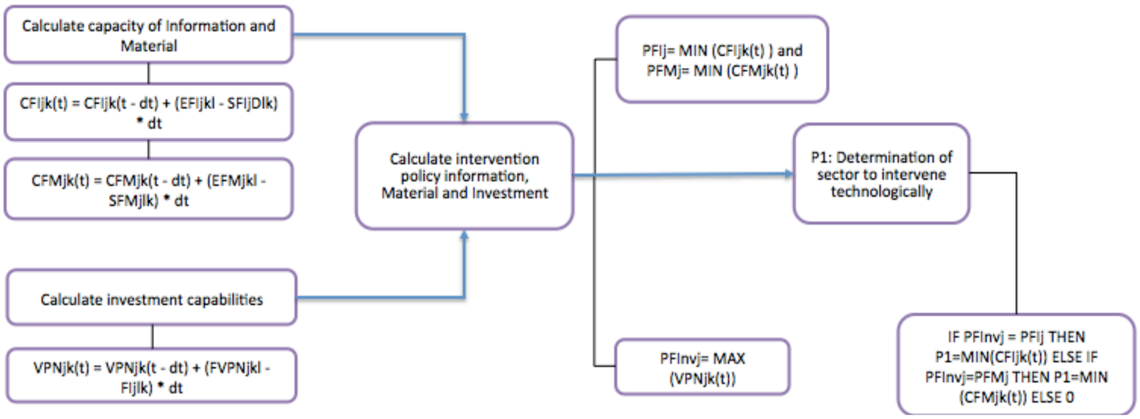

Figure 10. Algorithm to determine the policy to intervene technologically area.

A second algorithm is designed to determine the technological alternative in accordance with the levels of technology that presents the company (old technology, new technology and technology development). The algorithm is presented in Figure 11.

i: *Alternative technology (acquisition, development, adaptation).*
k: *Subscript represents a level type k.*
TIR (i): *Internal Rate of Returns type of alternative i.*
CP (i): *Cost of alternative type i.*
Nik (t): *State (level) of alternative type i.*
NPVi: *Net Present Value of type alternative i.*

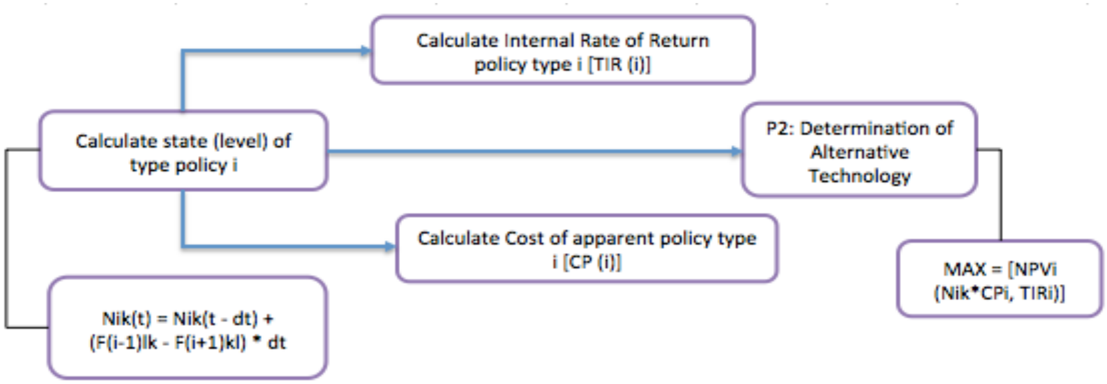

Figure 11. Algorithm to determine the policy alternative technologically.

The mathematical model supports the structure of each sector simulation, whereby a dimensional analysis of the mathematical model presented is conducted.

Simulation Model Validation

In order to verify that the designed simulation model presents a representative of the real system behavior are performed statistical tests for comparison of means and correlation of the actual system demand and the demand simulated by the model. As well, was performed Test error rate on the average percentage error and the variation proposed by Barlas (1989).

At this stage were defined the parameters of average quality (real) generated in the pulp production (e.g. blackberry), with which the simulation is set in a period of 48 weeks (1 year). From this, the following hypothesis is proposed for validation through a statistical test for comparison of means between the actual and simulated variable-demand system:

$$H_o: \boldsymbol{\mu_R = \mu_S}$$
$$H_i: \boldsymbol{\mu_R \neq \mu_S}$$

H_0: *The average actual demand is the same simulated system demand.*
H_i: *The average actual demand differs from the simulated system demand.*

According to the results in Table 1 was decided not to reject the null hypothesis, and it is concluded that a 0.05 significance level data can not determine that there are differences between kilograms of real system with respect to the simulated.

Table 1. Comparison of mean demand for pulp (real vs. Simulated).

ANOVA

IDPTk

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	7405,639	35	211,590	1,609	,191
Within Groups	1578,170	12	131,514		
Total	8983,809	47			

$F_{0,05;12,35}$ =2,041>1,609 Do not Reject Null hypothesis

In this way the statistical test of correlation in demand for pulp in the Table 2 to measure the relationship between real and simulated data shows a positive correlation (0.306) and a suitable value of significance (p-value = 0, 05> 0.034).

Table 2. Correlation of demand for pulp (real vs. Simulated).

Correlations

		DemMora	IDPTk4
DemMora	Pearson Correlation	1	,306(*)
	Sig. (2-tailed)		,034
	N	48	48
IDPTk	Pearson Correlation	,306(*)	1
	Sig. (2-tailed)	,034	
	N	48	48

* Correlation is significant at the 0.05 level (2-tailed).

The next section presents the model of the Fuzzy Inference System applied in the parameters representing the delay (setup time-picking and time-tracking data) in the system.

Integration System Dynamics - Fuzzy Inference System

The integration System Dynamics and Fuzzy Inference System is made through the variables forming the causal diagram. These have an effect on the parameter study (setup time in the areas of supply chain fruit) with some uncertainty (positive, negative or medium effect). In the case of Figure 12 setup time picking operations in the sector of raw material supply is affected by the variables: products, amount of raw material required and number supplier.

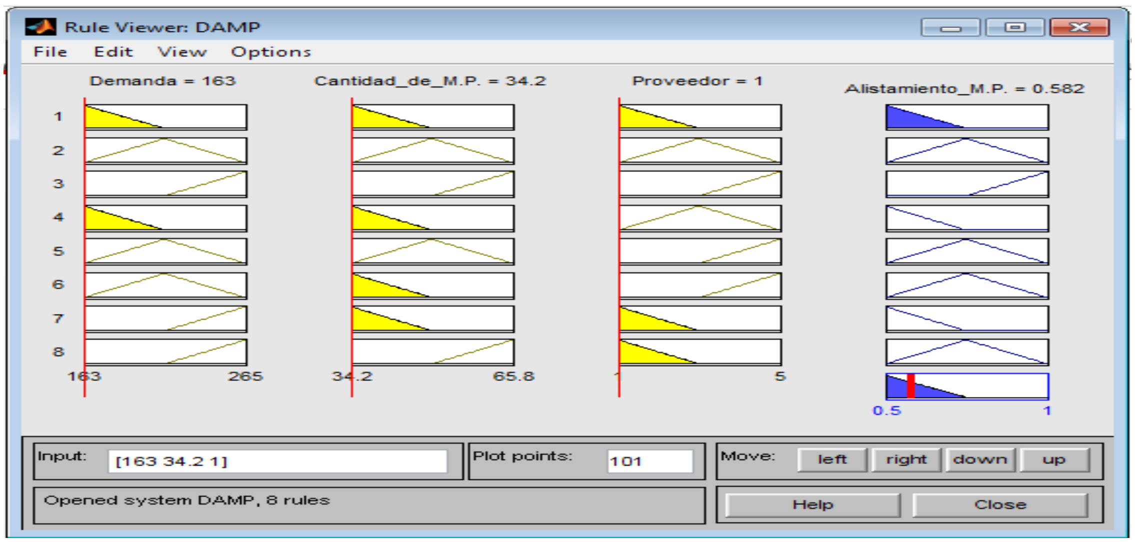

Figure 12. Fuzzy Inference System-Time picking supply sector

After obtaining the values of different effects (negative, positive and means) takes the lower value of setup time (DAMP, DAPP and DAPD) and simulations with these values are performed in order to obtain the behavior in the variables used in decision-making. Figure 13 shows the behavior of the information flow policy of RFID technology with the parameters obtained from the Fuzzy Inference System, which represents a better stable performance compared with barcode technology is presented in Figure 14.

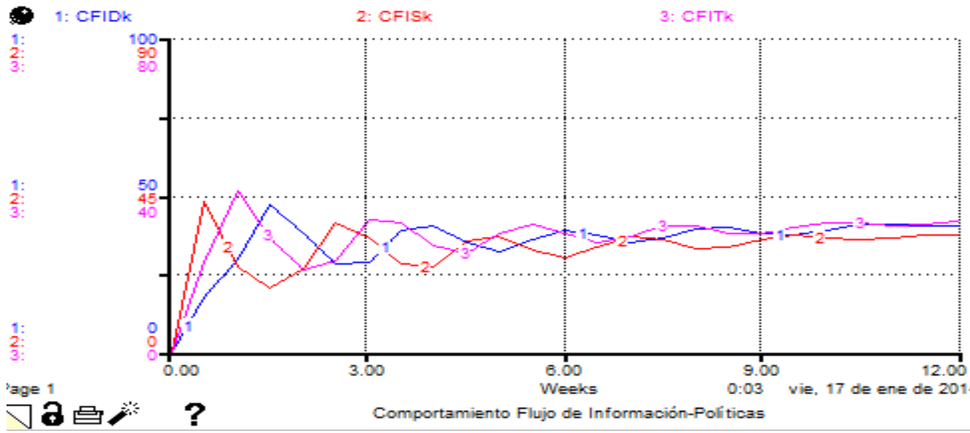

Figure 13. Flow Behavior Information Technology RFID with fuzzy parameters.

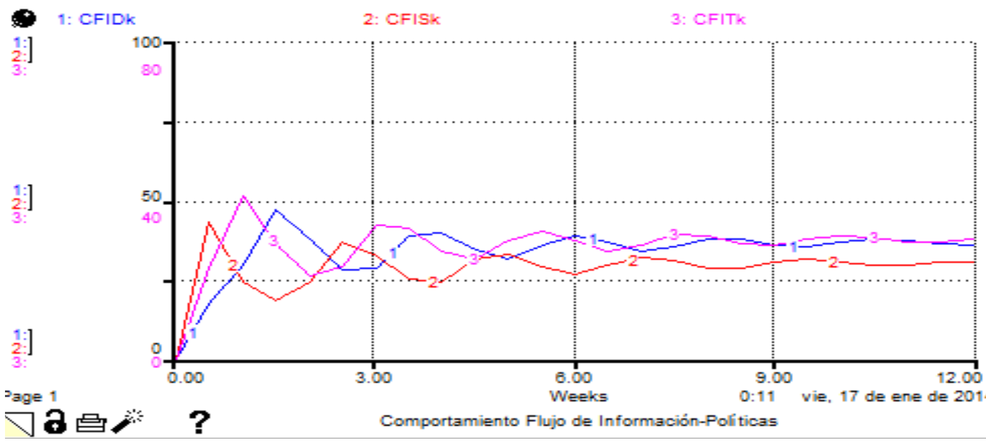

Figure 14. Flow Behavior Information Technology Barcode with fuzzy parameters.

The results of the integrated System Dynamics and Fuzzy Logic model are presented.

Results Integrated Model-DS and Fuzzy Inference System

The results of Integral and Dynamics Fuzzy Model address two aspects: traceability (quality) and picking operation (logistic). First sensitivity analysis taking into account the technology management policies, later measures performance to the simulation model, and finally the integration of the fuzzy logic methodology and System Dynamics.

Sensitivity Analysis for the lead-time parameter

Sensitivity Analysis of the simulation setup time variable used in each sector is selected, as shown in Table 3, it presents a comparison between the RFID tracking system and barcodes. Addressed the setup time (DAMP, DAPP and DAPD) in three states show better efficiency in the flow capacity of RFID traceability systems with shorter enlistment in the areas of simulation supply chain.

Table 3. Sensitivity Analysis –time picking operation vs. capacity planning technology.

	Time Picking Operation by sectors			Flow Capacity Information-CFI (Batch)		Flow Capacity Material- CFM (Kg/Und. Technological)	
State	DAMP	DAPP	DAPD	RFID/EPC	Barcodes	RFID/EPC	Barcodes
1	0,5	0,5	0,7	86,62	78,25	1,5	1,5
2	0,75	0,75	0,725	0	0	1,45	0
3	1	1	0,75	50,69	34,31	1,4	1,4

In the case of Figure 15, the graph represents the behavior of stabilization system for tracking technology employs barcode (simulation: 1, 2, 3), and RFID / EPC technology (simulation: 4, 5, 6). After several runs are identified that lower data transmission time in the fields of simulation, the technology has a better behavior is stable RFID / EPC compared barcode contrast improves when the transmission time data is high.

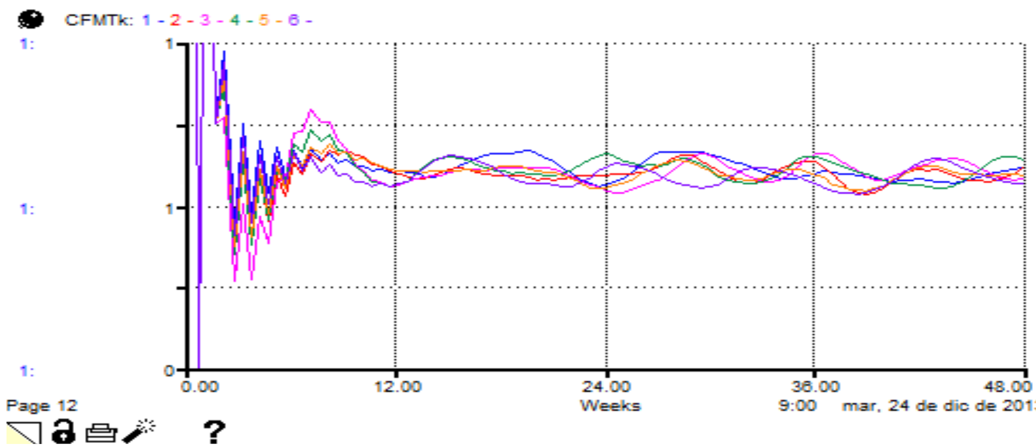

Figure 15. Sensitivity analysis - time data transmission vs. Flow Capacity Material in Supply Chain

Table 4 summarizes the changes in the simulated investment time parameter, the highest Net Present Value (NPV) of the investment is made for the two technologies in the shipping sector; industry that matches the policy for determining the area in which to invest. These values reflect the phenomenon having the system stability after the third month.

Table 4. Sensitivity analysis-time investment by sector vs. technology planning capabilities

	Time (Delay) Investment by sector			Net Present Value Investment- Shipping Sector (VPNDk)		Net Present Value Investment- Supply Sector (VPNSk)		Net Present Value Investment- Manufacturing Sector (VPNTk)	
State	TIS	TID	TIPT	RFID/EPC	Barcodes	RFID/EPC	Barcodes	RFID/EPC	Barcodes
1	1	1	1	2563,71	2550,98	592,99	592,35	2174,7	2174,7
2	2	2	5	2675,39	2674,83	594,69	594,27	2174,7	2174,7
3	3	3	9	2675,85	2674,89	594,84	594,48	2174,7	2174,7

Finally, sensitivity analysis is performed on the parameters associated with the selection policy of technological alternatives in the supply chain. The alternative technology of less NPV associated with traceability RFID this indicates that alternative development is not suitable, however the alternative technology purchasing has a better stability in the NPV, indicating that the alternative technology policy, as a result sheds technology purchases in the state of simulation 1 (see Table 5).

Table 5. Sensitivity analysis-Internal Rate of Return for technological alternative.

	Internal Rate of Return for alternative technology			Alternative Development-ADT		Alternative Buy-ANT		Alternative Adaptation-AAT	
State	TIRAT	TIRCT	TIRDT	RFID/EPC	Barcodes	RFID/EPC	Barcodes	RFID/EPC	Barcodes
1	0,09	0,008	0,08	7237,05	7033,88	121646,03	122079,31	20074,42	20315,9
2	0,11	0,0387	0,103	5625,07	5499,75	25721,62	25996,36	16931,33	17098,62
3	0,13	0,0693	0,127	4612,73	4532,84	14575,1	14765,87	14775,47	14892,22
4	0,15	0,1	0,15	3920,82	3869,4	10351,43	10492,19	13205,97	13287,13

Then the results of the performance measures of the simulated system are presented.

Results Performance Measures-Simulated System

Performance measures were evaluated for traceability technologies RFID / EPC and Barcode comparing implementation through performance indicators designed for each sector of the fruit supply chain. The performance indicators traceability technology for barcode shows an increase in the Information Flow Grade-GFI also affects the increase Traceability Grade-GT. In this way, the indicator System Reliability Technology Traceability CSTT presents a stable behavior over time of 74% (see Table 6).

Table 6. Sector Performance Indicators-Traceability Technology: barcode.

	Information Flow Grade- GFI	Performance Technology -DT	Traceability Grade sectors -GT	Using Margin (Kg)	Investment Growth Rate ($US/week)
Supply	1,26	0,25	0,77	0,22	0,50
Manufacturing	1,02	0,32	0,71	0,29	0,22
Shipping	1,60	0,49	0,83	0,2	0,22
System Reliability-CSTT	0,74				

The behavior of the indicators of the RFID tracking technology shows an increase in the Information Flow Grade-GFI also affects the increase Traceability Grade-GT, indicating that the RFID tracking technology has a greater capacity in the information flow. The growth delay GFI provides adaptive technology traceability therefore its growth is slower. In this way, the indicator System Reliability Technology Traceability CSTT presents a stable behavior over time of 89% is presented in Table 7.

Table 7. Sector Performance Indicators-Traceability Technology: RFID / EPC.

	Information Flow Grade- GFI	Performance Technology -DT	Traceability Grade sectors -GT	Using Margin (Kg)	Investment Growth Rate ($US/week)
Supply	1,24	0,38	0,96	0,18	0,40
Manufacturing	1,04	0,46	0,85	0,12	0,18
Shipping	1,55	0,67	0,93	0,17	0,18
System Reliability-CSTT	0,89				

In conclusion, RFID tracking technology compared to barcodes presents a behavior system reliability traceability technology (CSTT) increased, this implies a substantial improvement in the flow of information, materials and capital, which is reflected indicators for each sector. In the following apart are presented results of Implementing Technology Model with a fuzzy logic system.

Results Fuzzy Logic System and System Dynamics

In this section is presented the results of the integration of System Dynamics and the Fuzzy Inference System. The purpose of this integration is to combine the skill of the conceptual model (causal diagram) and use fuzzy simulation parameters (knowledge base) to improve the decision making process of a complex system with some degree of uncertainty in causal variables. In the case of fruit supply chain objective focuses on improving times associated enlistment picking operations (logistics) and the transmission times of the data (quality).

In this sense, the causal diagram variables (input variables) were used which have an impact on the simulation parameters, setup time (picking), the output variable of the Fuzzy Inference System (see Table 8). At the stage of defuzzification of the output values taking time enrollment in picking operations (DAMP, DAPP and DAPD) expert qualitative variable (fuzzy inference system) is associated.

Table 8. Fuzzy Logic System for simulation parameters under System Dynamics.

Input					*Output*				
	Parameters			*Membership Function*	*Parameters*			Value Desfusificado	
Variable	*a*	*b*	*l*		*a*	*b*	*l*		
Demand	163	214	265	*Triangular*	0,5	0,75	1	0,582	Low
Raw Material	34,2	65,8	50		*Triangular*			0,75	Mediu
Supply	1	3	5		DAMP			0,75	
Fruit Manufacturing	2	2,5	3	*Triangular*	0,5	0,75	1	0,582	Low
Production Order	13	192		*Gaussiana*	*Triangular*			0,75	Mediu
Storage process	0	50	100	*Triangular*	DAPP			0,918	High
Productive Capacity	0,064	0,12		*Gaussiana*					
Sales	102	112	122	*Triangular*	0,7	0,725	0,75	0,708	Low
Customers	11	20	29	*Triangular*	*Triangular*			0,725	Mediu
Enlistment	13	128		*Gaussiana*	DAPD			0,742	High

In line with the development of the integrated model output values of fuzzy inference system is defusificar and the minimum of setup time (picking) in the system dynamics simulation is replaced, which improved the capabilities of information flow and material flow (see Table 9).

Table 9. Comparison of parameters (input) and capacity (output) of the Fuzzy System and System Dynamics.

	Setup time (minimum)			RFID/EPC	Barcode	RFID/EPC	Barcode
State	DAMP	DAPP	DAPD	Flow Capacity Information-CFI (Batch)		Flow Capacity Material- CFM (Kg/Und. Technological)	
Integral and Dynamics Fuzzy	0,582	0,582	0,708	90,6	82	1,9	1,7

System Dynamics	0,5	0,5	0,7	86,62	78,25	1,5	1,5
Example Company	0,8	0,8	0,7	N.D.	78	N.D.	1

N.D.: Data not available from the Example Company.

The real system (research company) has a setup time in the picking operation of 362.88 min / week on average (4.8 days / average * 75.6 min / day), compared with the Integral and Dynamics Fuzzy Model with a time of enlistment of 264.6 min / week on average (3.5 days / average * 75.6 min / day).

Conclusions

The relationship of the actors in the fruit supply chain is framed in different dynamics that govern their behavior. In this sense, the market dynamics traceability technologies in supply chain presents a growth that generates impacts on flows of material, information, capital, human resources and money. Therefore, the implementation of traceability technologies in the food supply chain requires models oriented comprehensive analysis of relationships and flows between the actors of the chain.

An increased logistics activity requires improvements for analyzing information using appropriate technologies to reduce the risk of contamination in the food supply chain. In this way the model developed allows analysis of relations between actors and contribute to the management of technology in the supply chain through logistics policies. The proposed integration from the conceptual model (causal diagram), the system dynamics simulation and applied knowledge base through a fuzzy inference system, allow you to associate the expertise of unit production company and the actors studio in the fruit chain (suppliers, processors and distributors), which allows to generate policies for implementing traceability technologies in fruit supply chain.

The implementation model of RFID tracking technology developed in this paper uses the methodology of System Dynamics and Fuzzy Inference Systems. The work previously developed with these methodologies do not outline the concept of comprehensiveness and integration from a conceptual model (causal diagram) so the knowledge base of the expert is not addressed from the perspective of uncertainty of causal variables related to the simulation model continuous. Whereas, the comprehensive and dynamic model developed here combines elements of complexity-uncertainty, causality-experience, knowledge-base-behavior and links the analysis of the causal structure by means of a Fuzzy Inference System. In this way, it is considered that the comprehensive and dynamic model is an innovative approach applied in the method used for the integration of simulation methodologies and expert systems.

Delays (time) generated in logistics readiness activities (picking) and traceability technology planning, influencing the performance of the fruit supply chain flows of material, information, human resources, capital and investment. The inclusion of simulation systems and fuzzy logic to analyze the uncertainty in the time associated with managing technology and logistics activities.

The performance indicators tracking technology designed for RFID and barcode shows an increase in the Grade Information Flow-GFI also affects the increase Traceability Grade-GT. This indicates how similar response of the system as the flow of information and materials. In this way, the indicator System Reliability Technology Traceability CSTT (grade tracking and monitoring) has a stable behavior over time of 74% for the traceability technology with barcode and 89% for RFID.

Referencias

Abo-Hamad, W., & Arisha, A. (2011). Simulation-Optimisation Methods in Supply Chain Applications: A review. *Irish Journal of Management* (116).

Amin, S., & Zhang, G. (2012). An integrated model for closed-loop supply chain configuration and supplier selection: Multi-objective approach. *Expert Systems with Applications , 8* (39), 6782-6791.

Asociación Nacional de Empresarios de Colombia-ANDI. (2012). *Encuesta Nacional Logística: Resultados Bechmarking Logístico* . Bogotá: ANDI.

Barlas. (1989). Multiple tests for validation of system dynamics type of simulation models. *European Journals of Operational Research* (42), 59-87.

Campuzano-Bolarín, F., Mula, J., & Peidro, D. (2013). An extension to fuzzy estimations and system dynamics for improving supply chains. *International Journal of Production Research , 10* (51), 3156-3166.

Campuzano, F., Mula, J., & Peidro, D. (2010). Fuzzy estimations and system dynamics for improving supply chains. *Fuzzy Sets and Systems , 11* (161), 1530-1542.

Carvalho, J. P., & Tome, J. A. (2000). Rule Based Fuzzy Cognitive Maps - qualitative systems dynamics. *Annual Conference of the North American Fuzzy Information Processing Society - NAFIPS* , 407-411.

Chao-Ching, C., & Min-Ping, K. (2010). Ambidextroux effects of relational specific investments in the OEM Transactions. *The 28th International Conference of the System Dynamics Society* .

Chen, K.-Y., Hwang, Y.-F., & Chen, M.-C. (2009). Applying RFID to Picking Operation in Warehouses in Global Perspective for Competitive Enterprise . *Economy and Ecology , Springer London*, 531-540.

Chen, Y. (2011). Understanding technology adoption through system dynamics approach: A case study of RFID technology. *Proceedings - 2011 IFIP 9th International Conference on Embedded and Ubiquitous Computing, EUC 2011* (art. no. 6104551), 366-371.

Dangelico, R., Garavelli, A., & Petruzzelli, A. (2010). A system dynamics model to analyze technology districts' evolution in a knowledge-based perspective. *Technovation , 2* (30), 142-153.

De Marco, A., Cagliano, A., Nervo, M., & Rafele, C. (2012). Using System Dynamics to assess the impact of RFID technology on retail operations. *International Journal of Production Economics , 1* (135), 333-344.

Dharmaraj, N., Rodrigues, L., & Shrinivasa Rao, B. (2006). Technology management in innovative organization: A system dynamics based perspective. *ICMIT 2006 Proceedings - 2006 IEEE International Conference on Management of Innovation and Technology , 2* (art. no. 4037182), 1059-1062.

Forrester, J. W. (1958). Industrial Dynamics: A Major Breakthrough for Decision Makers. *Harvard Business Review , 36* (4), 37-66.

Frazelle, E., & Sojo, R. (2007). *Logística de almacenamiento y manejo de materiales de clase mundial*. Bogotá D.C.: Norma.

Ghazanfari, M., Jafari, M., & Alizadeh, S. (s.f.). An Approach to solve fuzzy system dynamic problem. Tehran: Iran University of Science and Technology.

Giraldo, D., Betancur, M., & Arango, S. (2010). Efectos de la disponibilidad de alimentos sobre la seguridad alimentaria. *VIII Congreso Latinoamericano de Dinámica de Sistemas* .

Guzmán, G., & Andrade, H. (2009). Una aproximación al tratamiento de la cualitatividad en dinámica de sistemas usando lógica difusa. *7º Encuentro Latinoamericano de Dinámica de Sistemas*.

Haleh, H., & Hamidi, A. (2011). A fuzzy MCDM model for allocating orders to suppliers in a supply chain under uncertainty over a multi-period time horizon. *Expert Systems with Applications , 8* (38), 9076-9083.

Herrera R., M., & Orjuela C., J. (2014). Perspective of Trazability in the Food Supply Chain: An approach from System Dynamics. *Revista Ingeniería Universidad Distrital*, 19 (2).

Herrera R., M., & M., B. F. (2010). Perspectiva de gestión de tecnología en redes logísticas. *VIII Encuentro Colombiano de Dinámica de Sistemas*.

Herrera, M., & Orjela, J. (2012). Evaluación de Tecnología de Trazabilidad en la cadena de suministro frutícola: un enfoque bajo dinámica de sistemas. *X Congreso Latinoamericano de Dinámica de Sistemas , 1*, 615-622.

Kalenatic, D. (2001). *Modelo integral y dinámico para el análisis, planeación, programación y control de las capacidades productivas en empresas manufactureras*. Bogotá D.C.: Universidad Distrital Francisco José de Caldas.

Kalenatic, D., & Gonzalez, L. (2009). El sistema de gestión tecnológica como parte del sistema logístico en la era del conocimiento. . *Cuadernos de administración , 39* (22).

Karikoski, J., Heikkinen, M., & Hämmäinen, H. (2009). Scenario analysis and system dynamics in new emerging technology research: Case mobile peer-to-peer content distribution. *1st International Conference on Advances in P2P Systems* (art. no. 5359108), 60-65.

Kosko, B. (1986). Fuzzy Cognitive Maps. *International Journal of Man-Machine Studies , 24*, 65-75.

Li, F., Zhu, Y., & Wu, H. (2013). Modeling and optimization of traceability system for agriculture products supply chain. *Advanced Materials Research* , 574-579.

Li, X., & Wang, X. (2010). A study of the function-based policy optimization in system dynamics model. *International Journal of Innovative Computing, Information and Control , 6* (6), 2847-2856.

Lian, Q., & Jia, S. (2012). Research on two-stage supply chain ordering strategy optimization based on system dynamics. *Advances in Information Sciences and Service Sciences , 4* (23), 16-24.

Luong, N., & Saeed, K. (1992). Food self-sufficiency in vietnam: a search for a viable solution. *System Dynamics Review* .

Matos Chain, R., & Nascimento, N. (2011). Difusão da innovaçao tecnológica-análise dinâmica de um modelo. *IX Congreso Latinoamericano de Dinámica de Sistemas* .

Mula, J., Campuzano-Bolarin, F., Díaz-Madroñero, M., & Carpio, K. (2013). A system dynamics model for the supply chain procurement transport problem: Comparing spreadsheets, fuzzy programming and simulation approaches. *International Journal of Production Research , 13* (51), 4087-4104.

Musango, J., Brent, A., Amigun, B., Pretorius, L., & Müller, H. (2012). A system dynamics approach to technology sustainability assessment: The case of biodiesel developments in South Africa. *Technovation , 11* (32), 639-651.

Mutingi, M., & Mbohw, C. (2012). Fuzzy system dynamics and optimization with application to manpower systems. *International Journal of Industrial Engineering Computations , 5* (3), 873-886.

Ng, T., Khirudeen, M., Halim, T., & Chia, S. (2009). System dynamics simulation and optimization with fuzzy logic. *IEEM 2009 - IEEE International Conference on Industrial Engineering and Engineering Management* (art. no. 5373149), 2114-2118.

Orjuela C., J. (2004). Modelo logístico Basado en Dinámica de Sistemas para la Cadena de Abastecimiento de la Sabana de Bogotá. Pereira: Universidad Tecnológica de Pereira.

Orjuela C., J., Calderon, E., & Buitrago, S. (2006). *La cadena agroindustrial de frutas: Uchuva y tomate de árbol*. Bogotá D.C.: Fondo de Publicaciones Universidad Distrital Francisco José de Caldas.

Orjuela C., J., Kalenatic, D., & Huertas, I. (2010). *Modelo Integral y dinámico para la gestión de empresas de servicios*. Bogotá D.C.: Universidad Católica de Colombia.

Pankaj, S. K. (1994). A fuzzy set theoretic approach to qualitative analysis of causal loops in system dynamics. *European Journal of Operational Research , 3* (78), 380-393.

Peidro, D. (2010). A fuzzy linear programming based approach for tactical supply chain planning in an uncertainty environment. *European Journal of Operational Research , 1* (205), 65-80.
Posada, J., & Franco, C. (2010). Acercamiento desde el enfoque sistémico a la problemática de seguridad alimentaria en la ciudad de Medellín: políticas para la superación. *VIII Congreso Latinoamericano de Dinámica de Sistemas .*
Puentes G., H. (2006). *Caracterización de la logística en Colombia*. Bogotá D.C.: Sena: Mesa sectorial de Logística.
Skoglund, T., & Dejmek, P. (2007). Fuzzy Traceability: A process simulation derived extension of the traceability concept in continuos food processing. . *Food and Bioproducts Processing , 85* (C4), 354-359.
Wolstenholme, E. (2003). The use of system dynamics as a tool for intermediate level technology evaluation: Three case studies. *Journal of Engineering and Technology Management - JET-M , 3* (20), 193-204.
Xu, J., & Li, X. (2011). Using system dynamics for simulation and optimization of one coal industry system under fuzzy environment. *Expert Systems with Applications , 38* (9), 11552-11559.
Yin, Q., & Xia, L. (2011). The knowledge transfer influence factors of industrial technology innovation coalition based on system dynamics research. *BMEI 2011 - Proceedings 2011 International Conference on Business Management and Electronic Information , 2* (art. no. 5918005), 684-688.
Zadeh, L. (1965). Fuzzy Sets. *Information and Control systems , 8*, 338-353.
Zimmerman, H.-J. (1983). Using fuzzy sets in operational research. . *European Jorunal of Operational Research* (13), 201-216.

Appendix A

GFID = DELAY (IDPTk/OCPTk,DAPD) ***(1)***
GFI: *Grade Information Flow (%)*
IDPTk: *Inventory of Finished Product Distribution (Kilograms).*
OCPTk: *Level Finished Product Purchase Orders (Kilograms).*
DAPD: *Delay associated picking Dispatched Product (weeks).*
DELAY: *Specifies the delay equation of the first order.*

DTMP = IMPk/TUMPk ***(2)***
DT: *Performance Technology (%)*
IMPk: *Raw Materials Inventory (Kilograms).*
TUMPk: *Traceability Technology Used in the field of Supply of Raw Material (Kilograms).*

CMP = RDMPk/LMPk ***(3)***
CMP: *Strengthening Capacity of Raw Material Supply (Kgs / Batch) sector.*
RDMPk: *Data Record Raw Material Used (Kgs).*
LMPk: *Level Number of Lots Raw Material Used (Batch).*

CSTT = (1-(1-DTD)*(1-DTMP)*(1-DTT)) ***(4)***
CSTT: *Reliability Technology in Traceability System* (%).
DTD: *Performance Technology in the Distribution sector (%).*
DTMP: *Performance Technology for Raw Materials sector (%).*
DTT: *Performance Technology in the Transformation sector (%).*

GTMP = OSMPk/RDMPk ***(5)***
GTMP: *Grade Raw Material Traceability (%)*
OSMPk: *Level order in Raw Materials Supply Process (Kilograms)*
RDMPk: *Data Record Raw Material Used (Kgs).*

MUTMP = TPMPk-TUMPk **(6)**
MUTMP: *Margin Using Traceability Technology in the sector Raw Material (Kilograms).*
TPMPk: *Planned Traceability Technology in the Supply of Raw Material sector (Kilograms).*
TUMPk: *Traceability Technology Used in the Supply of Raw Material sector (Kilograms).*

PNTP = (CNTPk*PNT) + (CTAk*PTA) **(7)**
PNTP: *Productivity Planned New Technology (Technological Units).*
CNTPk: *New Capability Level (Purchased) Planned Technology (Technological Units).*
PNT: *Productivity New Technology, (%).*
CTAk: *Capability Level Old Technology (Technological Units).*
PTA: *Old Technology Productivity (%).*

TCIS = DELAY3 ((CITSk/TUMPk)*GPMPkl, TIS) **(8)**
TCIS: *Growth Rate of Investment in the supply sector (US Dollars / week).*
CITSk: *Capacity Supply Technology Investment ($).*
TUMPk: *Traceability Technology Used in the Supply of Raw Material sector (Kilograms).*
GPMPkl: *Degree of Traceability Technology Planning in the Raw Materials sector(Kg / week)*
TIS: *Time Delay for Investment in the Supply sector, (week).*
DELAY3: *Specifies the delay equation of the third order.*

Appendix B

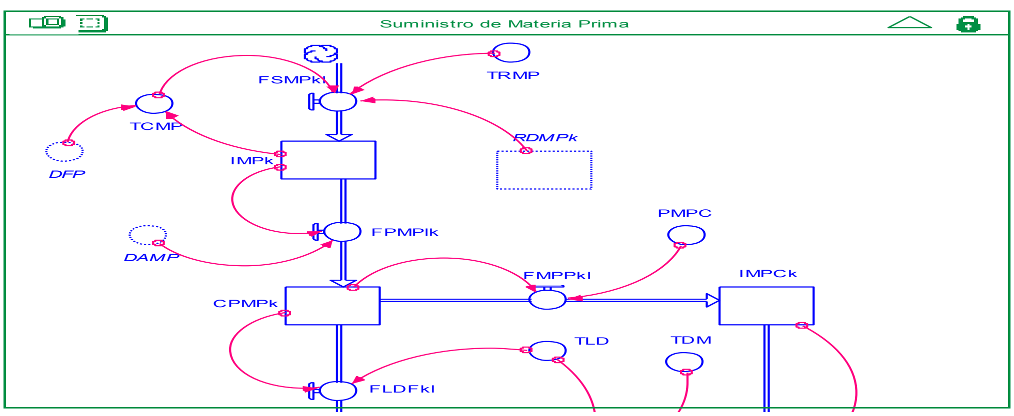

Figure 16. Forrester Diagram Sector-Supply of Raw Material Supply Chain

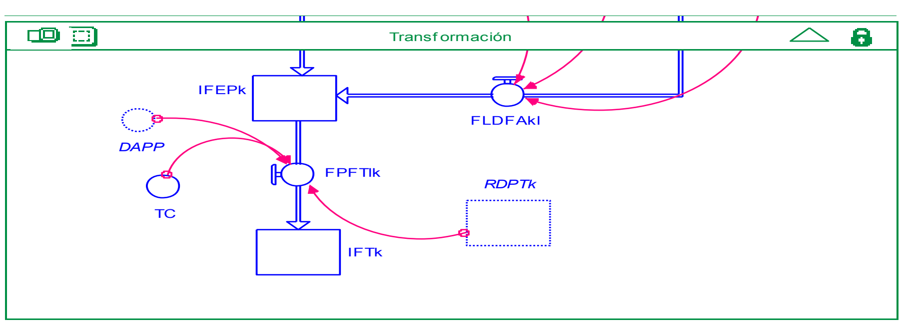

Figure 17. Forrester Diagram Sector-Supply Chain Transformation

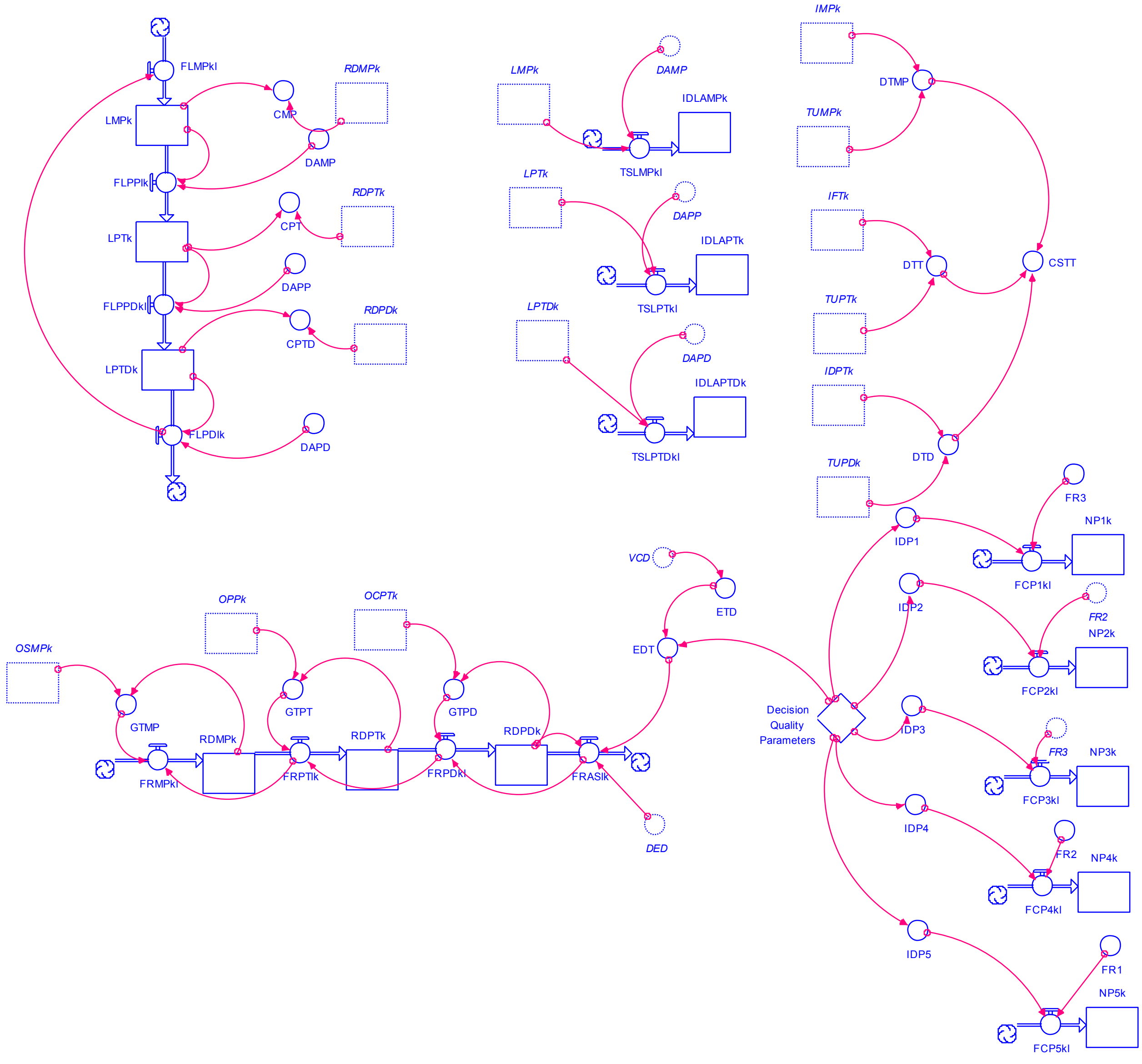

Figure 18. Forrester Diagram Traceability Sector- Traceability System

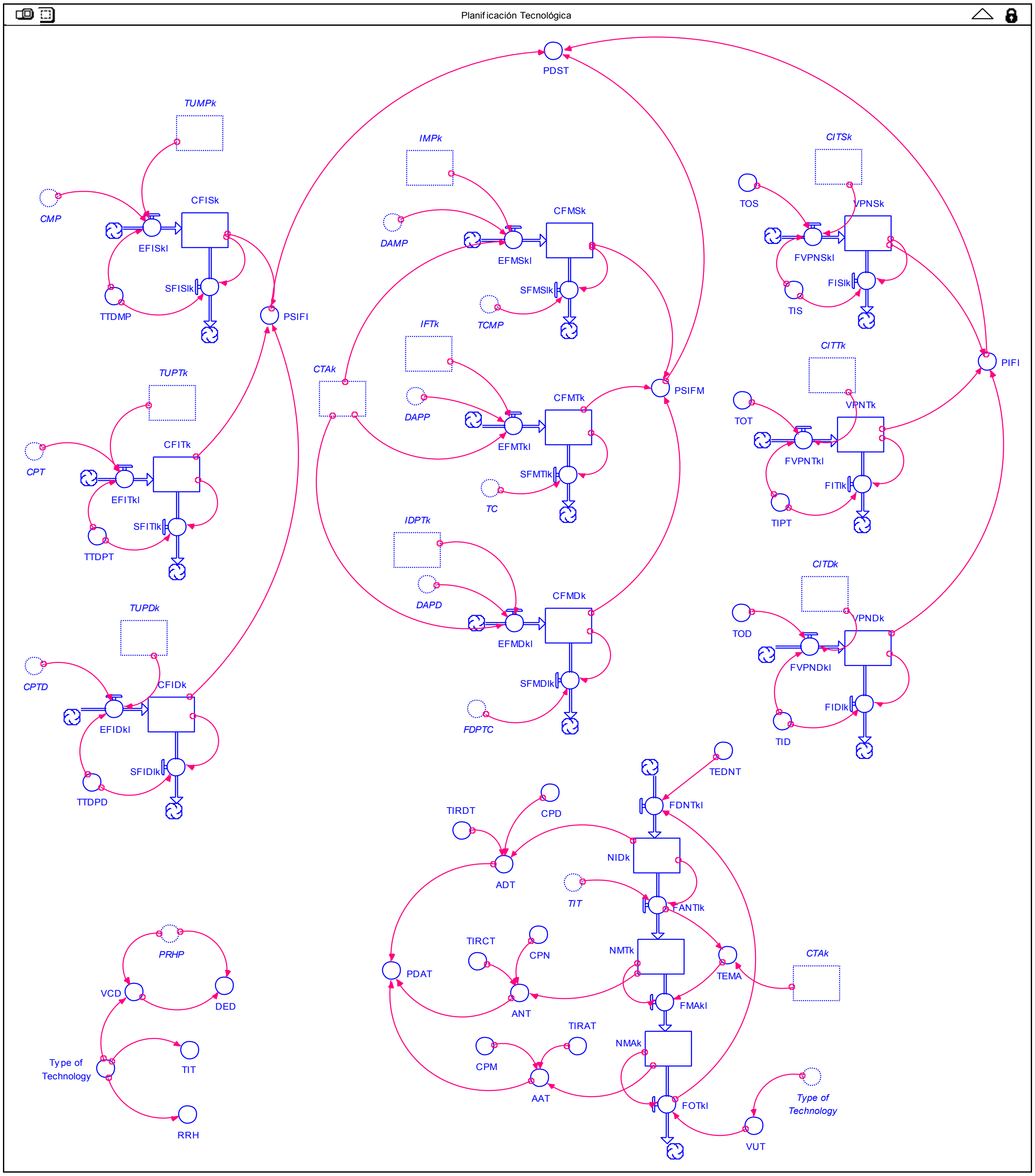

Figure 19. Forrester Diagram Sector Technology-Technology Management Planning