Inventory Management Analysis under the System Dynamics Model

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***Abstract*—In this work, the modeling of the system dynamics concerning inventory management has been carried out, this was done to achieve a correct analysis on said management, and thus make decisions that benefit the company. Knowing that the problem lies in the mismanagement of inventories, which are managed by certain companies with little or vast knowledge about inventory management, for which, it is desired to make use of the system dynamics modeling, so that this, achieves a correct analysis of the management, but is focused on the dynamics of system. The result obtained, from the development of the methodology applied in this work, was a correct and adequate analysis of the dynamics modeling of system in inventory management, which was achieved, using the simulation software known as Vensim, and a methodology based on three stages that are the Causal Diagram, the Forrester Diagram, and the mathematical equations.**

***Keywords*—Causal diagram; dynamics of system; forrester diagram; inventory management; Vensim**

I. Introduction

The systems dynamics model [1] in these days that we live are very useful since this helps in understanding the processes that real systems have, some of these being complex and difficult to understand, that is why the system dynamics model helps us in decision-making in the strategic and tactical field, all this is done by making use of simulation.

This system dynamics model [2] can show different states of difficulty, therefore, it is convenient to know well what you want to analyze, for which we have to select the topic (It has to be oriented to the problem that you want to address), identify the variables, determine the limit (In the future how far we want to go in the behavior of the system and in the past to know what were the ultimate causes that originated the irregular behavior), build the causal diagram (To observe the relationships of the variables), construct the Forrester diagram and finally enter the equations so that a correct analysis can be carried out that gives us the ability to have a clear idea of the system in question [3].

As we already have a clear idea of what the system dynamics model is, in that case, it can be said that the word "system dynamics model" is a kind of "important" instrument that can be used correctly an endless number of systems [4]. It can also be added, as mentioned previously, that the system dynamics model gives a clear idea of complex systems, this is done using the computer as a means, by which the simulations of the systems are carried out [5], for these formulas are created that are entered into the system dynamics model, to later learn from the results obtained, and thus, be able to predict the behavior of the system over time. According to the article [6] in Cape Town in the country of South Africa, a study was carried out to determine the effectiveness of inventories managed by SMEs (Small and medium-sized enterprises), this study focused on the manufacturing industry, where Questionnaires were collected from 21 SMEs (Small and medium-sized companies), the results obtained were that most of these 21 SMEs (Small or medium-sized companies) knew the inventory management systems, but did not use it to its full capacity.

According to [7] in the City of Piura in Peru, there is underused land, which can be an option for urban farmers, where these lands could be used for urban agriculture, this is based on the risk management of Urban agriculture should complement new policies, based on clear issues, such as mismanagement of their inventories, which consequently results in the poor quality of products.

The objective of this work is to analyze the system dynamics model corresponding to inventory management using Vensim software that allows us to make causal diagrams and simulation through scenarios.

In Section II the literature will be reviewed, in Section III the methodology that will be used, in Section IV the results and discussions, and finally in Section V the conclusions.

II. Literature Review

In this section, the fundamental material for the resolution of this paper is explained, citing articles that have to do with inventory management, as well as model articles with system dynamics that are related to the topic to be treated in this paper.

It started with the article [8], which tells us about the inventory inspection, it mentions its importance, which is to help know the availability of the goods using the "count", it is like that, what could be said that the inventory is the "products that are acquired", and these may be raw materials (Trade companies and manufacturing companies), products in the process (Manufacturing companies), finished products (Manufacturing companies) and consumables (Service companies); He also comments on inventory management, which seeks to optimize sales and lower the cost of inventories.

Another article [9], makes a mention of the scarce demand that hospitals have, which generates economic consequences and consequently havoc in the care provided to patients, that is why here it is noted that there is a shortage of medicines (Mismanagement of inventories), it will occur, that the process of recovery of patients is delayed, for which it will have to place an order for emergency delivery, which will cause the cost to increase; He also mentions their use of the system dynamics model, where they developed their diagrams of causal loops, their graphs, tables and equations, of which they mention that they obtained positive results.

There is also an article [10], which writes about the benefits obtained by applying the system dynamics model, it mentions that the model is used to observe behavior over time, where alterations can occur, implying that the system dynamics model solves complex challenges; here they also generate their causal diagram, Forrester diagram, equations, tables, and graphs; but concerning the manufacturing industry.

Finally, there is an article [11], where they talk about the use of the system dynamics model, but to use it as an examiner, which means that they have used the system dynamics model to analyze the returned products It should also be mentioned that these returned products generate reverse logistics, which is responsible for analyzing what is going to be done with this “product return” and deciding when and how certain “actions” will be applied, among its “actions”, We have restoration, partial remanufacturing, recycling of raw materials and disposal; They are also using the analysis under the system dynamics model to know which parts of this returned product will be accepted for the production of a new product, in turn determining which parts of this returned product are subjected to another type of control; your causal loop diagram, Forrester diagram, tables, and graphs were also generated here.

III. Methodology

In this section, the systems dynamics methodology that was carried out in the model carried out in Vensim is explained, a methodology based on the causal diagram was used, followed by the Forrester diagram and at the end, the equations were shown, achieving thus the objectives, thanks to the support of this methodology.

As mentioned, the model is made in Vensim, which is a simulation software that has modeling capabilities, the model based on Vensim, takes the real systems as a base to perform the simulation, and in this way show the dynamics model systems that are very beneficial, since it solves the needs for understanding the “processes” that real systems have, that is why the system dynamics model is an important instrument, since it is correctly accommodated with the system. What Vensim did is carry out the simulations of the systems, but to achieve this development correctly, formulas were added that were entered into the Forrester model so that when executing this model, the knowledge that it provides can be assimilated when generating the tree and graph of causes, as well as graph and table by selected variables; and in this way achieve a forecast of the behavior of the system based on a certain period.

A. Causal Diagram or Dynamic Hypothesis

A causal diagram said colloquially is based on variables that are linked by arrows that represent the causal relationships between the variables, to these “arrows” a positive (+) or negative (-) sign is added, to indicate the change that occurs in the dependent variables at the time the independent variables change, this can be seen in Fig. 1, where the arrow represents the causal relationship between the independent variable “Purchase Order” and the dependent variable “Supply Line”, Which tells us “the more purchase order, the more supply line”, but if we generate the change in the independent variable and say “the less the purchase order” would result in “less supply line”, which makes change the sign of the arrow representing the causal relationship to the negative sign (-).

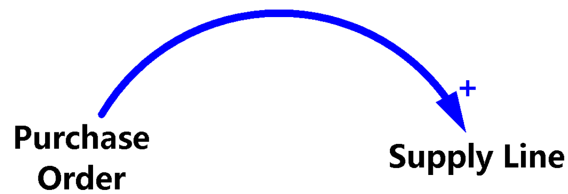

Fig. 1. Causal Diagram

It can also be said that a causal loop diagram, within each loop, has a type of loop that rotates in the same sense of the loop to which it belongs, this sense can be clockwise or counter-clockwise; Likewise, this type of loop is divided into two types, the first known as “Snowball or reinforcing feedback loop (positive)” which is a process in which a “variable a” reinforces a “variable b”, and in turn, this “variable b” reinforces the “variable a”, doing this in an unlimited way, we can see this in Fig. 2 and the second known as “Balance or compensating (negative) feedback loop” that It is a process that tries to obtain an equilibrium, this can be observed in Fig. 3, it is worth mentioning that a causal loop diagram applied correctly allows the creation of a beneficial model for the study of a real system, since it can to assertively assist in the planning and process of the system operations in question, this will later be used to develop the Forrester diagram. One point to highlight is that, for the resolution of this paper, the causal diagram of the reference [12] will be used, which we can see in Fig. 4.

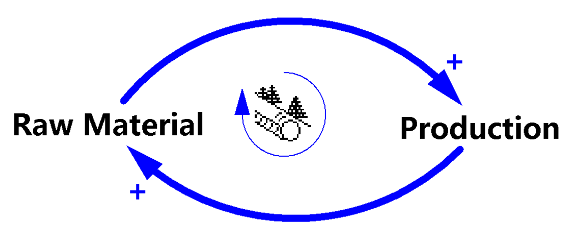

Fig. 2. Reinforced Feedback Diagram

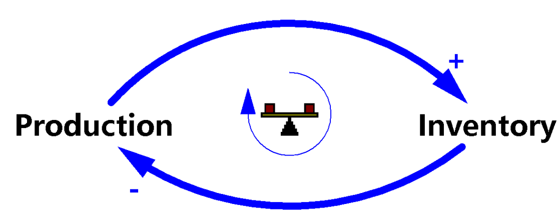

Fig. 3. Compensating Feedback Diagram

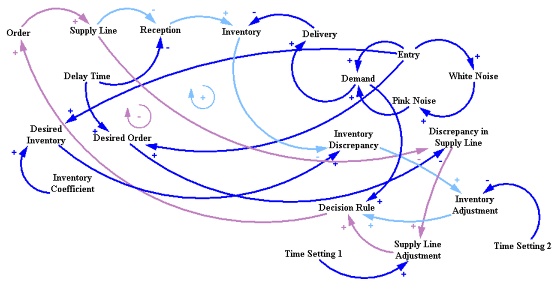

Fig. 4. Inventory Model Causal Loop Diagram

Fuente: [12]

B. Forrester Diagram

In this section, the causal loop diagram is seen in Fig. 4 was used to make the Forrester diagram, as mentioned previously, for this, the variables and the “arrows” were copied identically since the “arrows” represent the causal relationships between the variables. In this Forrester diagram, the types of variables were identified, to which the variables are shown in Fig. 4 belong, that is why in this section the types of variables were known, the first known as a level of stock variable, which it will only change through the flow, if the inflow is higher than the outflow the level will increase, otherwise the level will decrease, it should be noted that the data in a level or stock variable always changes over time; the second known as the exchange rate or flow variable (inflow and outflow), which is in charge of filling the level or stock variable, as the level of the stock variable was mentioned, it can only be changed by the variable flow (Flow in and flow out); and finally the auxiliary or converter variable, which serves as a support for the model and the exchange rate or flow variables (inflow and outflow), making the model more understandable. One point to highlight is that for the resolution of this paper, the Forrester diagram of reference [12] will be used, which we can see in Fig. 5.

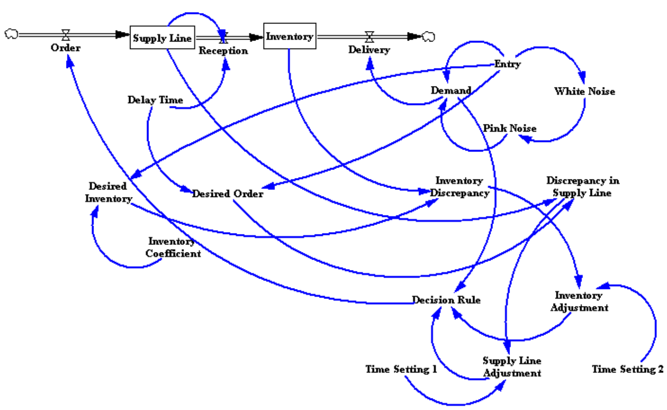

Fig. 5. Forrester Diagram of Inventory Model

Fuente: [12]

C. Mathematical Equations

This section shows the inventory model system but represented by mathematical equations, these mathematical equations are the ones that were entered in each of the variables established in the Forrester diagram, both in the level or stock variables and in the exchange rate or flow variables (inflow and outflow); it should be noted that each of these variables was set their data types corresponding to each of them, this in the simulation software known as Vensim is done through functions, the functions that were used for the inventory model system (Not to mention data type functions) can be seen in (6), (21) and (22).

$$Inventory(t) = Inventory(t-dt) + \left(\substack{Reception \\ -Delivery}\right)dt \tag{1}$$

Where:

$$Inventory = Inventory\ Coefficient \times Entry \tag{2}$$

$$Reception = \left(\frac{Supply\ Line}{Delay\ Time}\right) \tag{3}$$

$$Delivery = Demand \tag{4}$$

In (2) the initial value of the level or stock variable known as Inventory is established, in (3) the equation of the exchange rate or flow known as Reception is established and in (4) the equation of the outflow is established known as Delivery; This initial value and these two equations are key for the Inventory level variable since to know the value of the Inventory variable that represents the “state of the system’s inventory”, it is necessary to know both the initial value of the Inventory as well as the equations of the flows that are “connected” to the Inventory variable.

$$Inventory\ Coefficient = 3 \tag{5}$$

$$Entry = 20 + STEP(20, 5) - STEP(20, 30) \tag{6}$$

The common + STEP ({height}, {stime}) function represents the increment in the value of the stream variable known as Input, but since time 5; while the common - STEP ({height}, {stime}) function represents the decrease in the value of the flow variable known as Input, but since time 30. Since it is known how the common function works STEP ({height}, {stime}), it can be said that (6) starts and continues with a value of 20, but when reaching time 5 to that 20, 20 more are added because the common + STEP ({height}, {stime}) function, which gave us a Continuous Input of 40, which changed when it reached time 30, which made that value of 40 be subtracted 20 less because the common - STEP ({height}, {stime}) function was used.

$$\begin{aligned} Supply\ Line(t) =& Supply\ Line(t-dt) \\ &+ (Order - Reception)dt \end{aligned} \tag{7}$$

$$Supply\ Line = 50 \tag{8}$$

$$Delay\ Time = 1 \tag{9}$$

$$Order = Decision\ Rule \tag{10}$$

$$\begin{aligned} Decision\ Rule = &Demand + Inventory\ Adjustment \\ &+ Supply\ Line\ Adjustment \end{aligned} \tag{11}$$

$$Inventory\ Adjustment = \left(\frac{Inventory\ Discrepancy}{Time\ Setting\ 2}\right) \tag{12}$$

$$\begin{aligned} Inventory\ Discrepancy =&Desired\ Inventory \\ &- Inventory \end{aligned} \tag{13}$$

$$Desired\ Inventory = Inventory\ Coefficient \times Entry \tag{14}$$

$$Time\ Setting\ 2 = 2 \tag{15}$$

$$\begin{pmatrix} Supply\ Line \\ Adjustment \end{pmatrix} = \frac{\begin{pmatrix} Discrepancy\ in \\ Supply\ Line \end{pmatrix}}{Time\ Setting\ 1} \tag{16}$$

$$\begin{pmatrix} Discrepancy\ in \\ Supply\ Line \end{pmatrix} = \begin{pmatrix} Desired\ Order \\ -Supply\ Line \end{pmatrix} \tag{17}$$

$$Desired\ Order = Entry \times Delay\ Time \tag{18}$$

$$Time\ Setting\ 1 = 3 \tag{19}$$

$$Demand = Entry + Pink\ Noise \tag{20}$$

$$Pink\ Noise = SMOOTHI(White\ Noise, 2, 0) \tag{21}$$

The common function SMOOTHI ({in}, {stime}, {inival}) represents exponential smoothing (Predicts demand in a set time), where the first parameter is the input value, which in this, In this case, it is the White Noise variable, the second parameter is the delay ti value, which in this case is 2, and the third parameter is the initial value, which in this case is 0.

$$White\ Noise = RANDOM\ NORMAL(0, 67779, 00.15 \times Entry, 0) \tag{22}$$

The common RANDOM NORMAL ({min}, {max}, {mean}, {stdev}, {seed}) function returns a random value from a normal distribution, where the first parameter is the minimum value, which in this case is 0, the second parameter is the maximum value, which in this case is 67779, the third parameter is the mean, which in this case is 0, the fourth parameter is the standard deviation, which in this case is 0.15 X Input and the fifth parameter is for the control of the pseudo-random number generator, which in this case is 0 since it is a value recommended by the Vensim simulation software.

IV. Results and Discussions

In this section, the scenario and the methodology that was applied for the preparation and resolution of this paper are shown, which is focused on the system dynamics model.

A. On Stage

In this graph in Fig. 6, you can see the status of the system inventory for a time expressed in months, this inventory started at 40, and then it decreased and increased until it reached 100 months, this can be seen in Table I, this decrease and increase in inventory are due to the Inventory X Input Coefficient, which was established in (5) and (6).

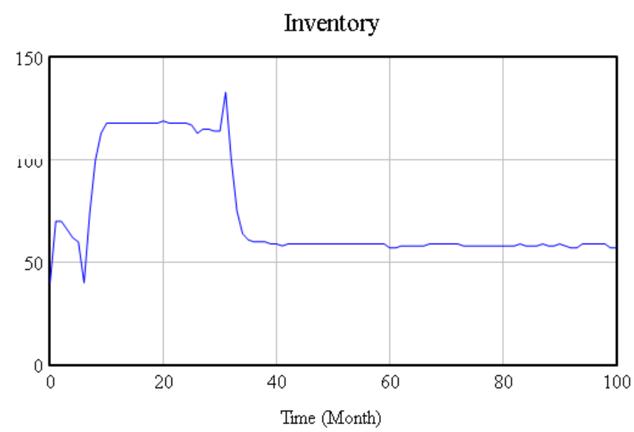

Fig. 6. Graph of the Inventory Level Variable

TABLE I. Time Down of the Inventory Level Variable

Month	Inventory
0	40
1	70
2	70
3	66
4	62
5	60
6	40
7	74
8	100
9	113
10	118

B. About the Methodology

The systems dynamics methodology [13], was very helpful, since it guided us, in the development of the model analysis, to begin with, it helped us to understand and develop the Causal Loop Diagram necessary for the system dynamics Concerning inventory management, besides, it also helped us to understand and develop the Forrester Diagram since it was easier to perform because it had the Causal Loop Diagram, it also helped us to establish the mathematical equations that the Forrester Diagram has, which was achieved, thanks to the fact that the Forrester Diagram in the simulation software known as Vensim [14], allows us to add these mathematical equations in a friendly way since if we want to use a function, this simulation software gives us a brief description of what will be entered in each of its parameters.

1) Advantages: The advantages offered by the systems dynamics methodology [15] are varied since thanks to its use it was possible to develop the analysis of inventory management under the system dynamics model, for which, we will begin by mentioning the Causal Loop Diagram, which thanks to this methodology allowed us to know the causal relationships between its variables [16], in addition to having an arrow to indicate the change that occurs in the dependent variables at the time the independent variables change. Also, thanks to this methodology, it was possible to develop the Forrester Diagram, where the types of variables were identified (variable level or stock [17], exchange rate variable or flow, and the auxiliary variable or converter), thus generating knowledge "good", since the identification of these types of variables help us to classify the variables found in the Causal Loop Diagram, another advantage of this methodology is the mathematical equations since this helps us to analyze the model of system dynamics, based on the operations and functions that were entered in the variables of the Forrester Diagram, thus achieving the fulfillment of the objective.

2) Disadvantages: One of the disadvantages of this methodology is the development of the system dynamics model of complex systems since an extensive study has to be carried out, so that this system works correctly in the system dynamics model, and not on the contrary, affect the project where the dynamics of the system is being carried out.

V. Conclusions and Future Work

This model of inventory management systems dynamics has gone through a series of successive states so that it progresses satisfactorily, and it is thus that it will help in the analysis of inventory management, since this analysis, produced through simulation software known as Vensim, it is suitable for designing causal models and Forrester models. Vensim simulation software was the tool used for the development of this system dynamics model, which managed to be efficient and valuable, both for the inventory management system that was used, as well as for the developer of this paper, already that this simulation software known as Vensim, helps to introduce a different view than the usual one since it shows us a model in Causal Diagram, a model in Forrester Diagram and mathematical equations, as well as a tree of causes, a document where the variables and values entered, are shown, a graph of the causes, a graph for selected variables and a table for selected variables. To make it clear, well understood and better perceived, it is noted that the methodology used performed and fulfilled its work and function perfectly, which served for a good development of the inventory management analysis under the dynamics model of systems, this being a set of successive key phases, to get to where you want in the intended objective in order to carry out the proposed, and thus guarantee and give security to the development of the system dynamics model. In future research, the system dynamics model could be implemented in other simulation software, such as Ithink or Stella, so that system dynamics researchers can know how each simulation software is used and when it is appropriate to use the simulation software in specific systems, and thus achieve a better understanding in the field of system dynamics.

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