Dynamics of Processing Time

Maximo Claudio Flores-Cabezas, Master of Science[1]
[1]Universidad Privada del Norte, Peru, maximo.flores@upn.edu.pe
[2]Desiree Diane Flores-Moya, Peru, u21102419@utp.edu.pe

Abstract*– The general purpose of this research is to show that the loading period in the processing of a product in the production line is the key factor for customer satisfaction in terms of quality and shorter lead time. Customers are increasingly requesting varied products, with varied models and shorter lead time. The decision maker takes this demand into consideration by controlling only the loading and download periods of the line and considers that the loading time is minimal and is not a limiting factor for delivering the order in the scheduled time. The objective through the development of causal and flow scenario models is to demonstrate that this time does influence the delivery of orders to customers. For this purpose, the variables and constants and the cause-effect relationships for the optimization of the loading period are identified. This research was developed experimentally, identifying and providing concepts of variables such as: demand, product, production line, operational sequence, standard time, setup, lead time, system dynamics, causal diagram, flowchart and its formulation. The results obtained through simulations with production units of 40, 20 and less than 5 units with variable times allow to decrease production lead times by 8.3% and 7.3%, respectively..

Keywords*-- production line, causal diagram, flow chart, variables and lead time.

I. INTRODUCTION

The current situation that is affecting the world economy due to the Covid crisis requires companies to focus on reducing costs, decreasing inventories and increasing the added value of their products with a faster response time and quality for customers in order to generate more income.

The company under study is formed in its production areas by clothing lines. Initially, the management decided that the areas, with their respective lines, should produce different types of products (t-shirts, shorts, sports pants, sports jackets, etc.) with several varieties of models of these products (e.g. t-shirts: long sleeve, short sleeve, three-quarter sleeve, etc., shorts: shorts with zipper, without zipper, without pocket, with pocket, etc.) without operational restrictions.

As it can be seen in Figure 1, a family is a product that is formed by a set of models. Each model varies in its design, and some type of applied pattern, such as embroidery or print, may also be added in the process. The degree of variability in its production is limited, since the model is part of a family and, if the quantity to be produced is continuous and high, due to the learning curve, the production line increases its level of efficiency, quality and productivity, reducing costs, since the workforce adapts quickly to the production of the model through experience and skill over time, as it can be concluded from figure 2:

- The greater the experience and skill of the personnel to perform the same operations of a variety of models of the same product, the shorter the time it takes to perform the activity, the greater its efficiency (a), the higher its quality (b), the lower its costs and the higher its productivity (c).

But if different types of families are programmed, as shown in Figure 1, to a given production line, as initially indicated by the management, the degree of difficulty in its production tends to increase and the behavior of the learning curve tends to be longer, due to the increase of reprocesses, costs and production times, and, as a consequence, there are continuous delays in the delivery of customer orders.

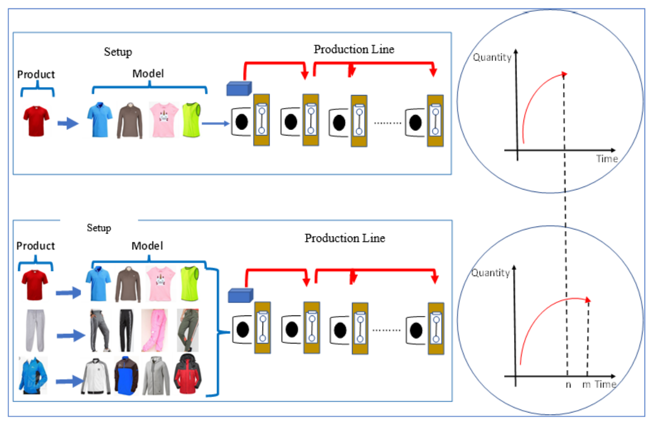

Figure 1: Learning Curve

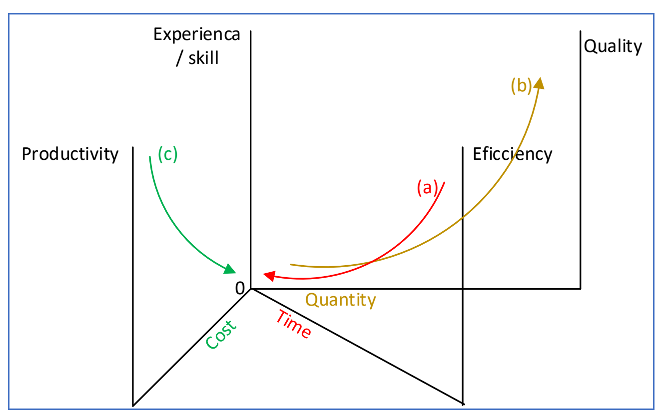

Figure 2: Experience and Skill vs. Quantity, Cost and Time

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LACCEI2022.1.1.199
ISBN: 978-628-95207-0-5 **ISSN:** 2414-6390

The operating personnel were dissatisfied with the way production scheduling was carried out on their lines, as it affected their efficiency, quality and income, because payment was on piecework basis, i.e. according to the quantity produced. The diversification of products in a production line makes it complex to increase the output speed, reduce production costs and satisfy customer requirements by meeting deadlines [1, 2].

Faced with such a situation, the management understood that it is allowed to make mistakes. It doesn't mean that failure is good, but that everyone in the organization should know that they can take risks to improve things, that the future of the company is directly proportional to customer satisfaction, and that decisions are not unique, but they should be adapted to customer needs. To this end, the organization focused on four categories representing influences on human behavior: the first one was related to the culture of the organization, the second one to the structure that should be developed, the third one to the incentives, and the last one to the personnel and their management.

The customer increasingly requested different types of models of one product, with degrees of variability in their manufacture, and the quantities requested were smaller and smaller, which required that production lines be flexible to the variety of models [3, 4, 5, 6}], fast in the input and output of production units, and that they comply with the quality characteristics. In this way, it would be able to meet customer demand.

Flexibility required that the operating personnel be skilled in performing different types of operations on different types of machines, but making one type of product with different models. To this end, the assignment methodology was modified, programming for each area one type of product and each area should assign to each production line one type of model of that product (see Figure 1). This allowed to increase productivity, efficiency and quality. The customer was more and more satisfied with the garments received because of the quality and punctuality, which was a sign of satisfaction and a guarantee to continue working, placing orders to the company.

Minimizing the LT will allow the line to increase the output speed for the production units, which will be reflected in the income of the company. For this, it is convenient to have the resources available: the person who will perform the production operation, the maintenance personnel to set up the machine and that the production unit be configured according to the garment or product model, and the inputs such as threads, needles, etc. The production system to be developed in the lines should change from push to pull system [7], which will allow producing according to customer demand, reducing unproductive times due to waiting.

As each area is assigned for the production of a certain type of product and each clothing line for a certain model of the product type, this allowed the area to have a good order and control, increasing its level of efficiency, quality, and reducing its lead time.

The determination of batches or production unit and programming of multiple models on a machine with setup times highlights that the objective is to establish batch sizes for each type of model, giving rise to production orders to be sequenced on a machine [8].

A. Statement of the Problem

In an environment where products, markets, operations and business models are constantly changing:

- How will the organization effectively integrate capabilities, resources and assets to be fast and agile enough to meet customer demand regarding quantity, quality and timing, and remain relevant in the marketplace?
- How will the collaborators in the operational area contribute to the generation of knowledge and adaptation to change within the organization in order to reduce the constant uncertainty of the market?

B. Objective

To make known the operational changes through conceptual development by the organization, with qualitative and quantitative scenario models to determine the processing time or LT of production units and to serve as analysis, evaluation and control to increase the speed, flexibility and adaptability to change models of garments, by production line.

To identify the variables and constants or parameters to be used as a control for the identification of time patterns (set up, adaptability of the operator when performing the operation, time to make the package with the number of garments configured) for each garment model to be developed in the production line, in order to perform its quantitative comparison and optimization.

C. Hypothesis

An organization that knows the activities taking place within a process and with abstract thinking will identify productive resources as variables and will develop qualitative scenario models, analyzing their cause and effect, and quantitative scenario models that will allow to determine, compare and optimize processing times or LT of the production units for each garment model, and this will contribute to increase the speed, flexibility and adaptability to change by the production line.

II. METHODOLOGY

This research was carried out in a company of the clothing industry, where the determination of Lead Time (LT) or processing time is made known by means of an empirical methodology. The collection of information, analysis and evaluation were carried out in different types of products and models, which allowed the organization to develop the scenario models through the system dynamics tool (SD) and to apply the model effectively obtaining the expected results.

The way to start managing the organization in production lines is when the area manager, having knowledge of the type of garment, analyzes and evaluates the technical data sheet or specification sheet. This document presents the following information: type of garment model, consumption of accessories, garment measurements, activities or operations to be carried out, standard times for each operation to be performed. With this information, the line balance is prepared, where the number of machines and personnel required is determined, as well as the start and end dates for the programmed quantity. This information is provided to the supervisor or person in charge of the line.

But the area manager does not take into consideration the loading period; he determines the production time for each of the activities by means of the inverse relationship between demand and production capacity per day (see figure 3).

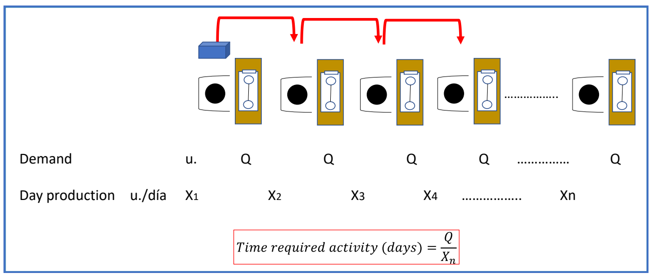

Figure 3: Production per day

For a good understanding of the present study, the following concepts will be presented:

A. Demand

It is the quantity of units required by the customer for a certain period of time. The company considers the customer's order as a production order that must be distributed to all operating areas, so that they know the quantity to be produced by color, size, model, type of fabric, type of pattern, among others. The area manager, based on the demand of the product model, determines the number of machines required to manufacture the garment, as well as the sequence and in which line the model will be produced. Normally machines distribution starts in the first operation of the garment production until its completion, and determines the production unit or batch that will be distributed in the production line.

$$Demand = f(model_{product}, Quantity, Time)$$

B. Product

It is the set of raw materials and inputs processed by the machine, human being or by using the two together. A product (figure 4), which is a garment, is formed by a set of models that are requested by the customer. The type of model varies according to the customer's needs, and this is normally presented according to the seasons of the customer's location. This product is previously produced by the product development area, with the objective of determining the sequence of operations to be executed in production, as well as the devices that the machines and/or equipment will require and the inputs the product will contain.

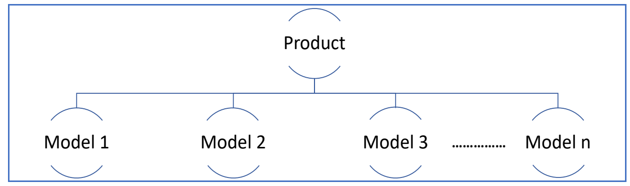

Figure 4: Model by Product

C. Production Line

A production line is composed by a set of workstations. Each workstation can be made up of man alone, machine alone or man and machine, arranged sequentially. Each station uses productive resources, raw material and inputs, workforce, machine, equipment, tools, etc., which allows it to meet an objective that is the processing of the production unit in a planned time according to the available time and the standard time of the activity, complying with the quality characteristic detailed in the technical data sheet, and it is done one production unit at a time, passing through all the stations that make up the production line.

The type of line set up is mixed, deterministic and dependent [9, 10, 11, 12], since it allows the production of several garment models of one basic product, i.e. the tasks executed are similar; deterministic, since the execution times of each task are known by surveying, analyzing and evaluating the times; and dependent, since the processing time depends on the number of stations on the line.

The ordering of the number of stations in a production line is in direct relationship to the operational sequence of the type of model, number of activities, duration of the activity, personnel availability, machine availability, flow of the production unit and the required infrastructure.

D. Operating Sequence (OS)

It is the pre-established sequence of a set of activities required for the production of a certain garment model, identifying the production unit and its content in pieces that make up a garment, and that will be sequentially distributed in the line.

The product development area, through its technical data sheet, proposes a certain sequence, which is validated by the production area when the first run is made on the line, in order to determine the type of machine setup and the degree of difficulty in its manufacture, as well as the number of inputs.

The activities that make up an operating sequence determine the type of production line setup, which can be linear, U-shaped, circular, among others.

Each activity that takes place in a workstation is executed within a time frame determined by the area manager or analyst.

E. Standard time

It is the time required to perform an activity. It is determined by considering the previously observed times, the valuation factor that marks the execution rate of the activity, and the supplement, which is the additional percentage assigned to the person who performs the activity under certain conditions established by the International Labor Organization (ILO). Andrade [13] states that companies that apply work studies are in a better position to be competitive, since their work is oriented to business effectiveness.

F. Production Unit

It is the minimum work expression developed in a production process, which is maintained since it enters the first workstation until the last station of production line. In the clothing industry, it is called production package. For the purposes of this research, we will call it a production "package".

The package contains a certain number of units in pieces. The number of units directly affects the feed rate per workstation in the production line, as shown in the following equation.

$$\text{Feed rate per workstation} = f(\text{\#units per package})$$

The quantity contained in a production package varies according to the garment model. If the garment is for adult sizes (XS, S, M, L, etc.), the quantity varies between 15 to 20 garments and, when the model is for children (12, 14, 16, etc.), the quantity of pieces per package varies between 20 to 40 garments.

For our study, we will use the letter "Q" to identify the number of units that make up a production package.

$$Q = \frac{Units}{package}$$

Figure 5 shows the behavior of times per package and presents a direct relationship. The more units that make up a package, the longer the time required for its processing in each station.

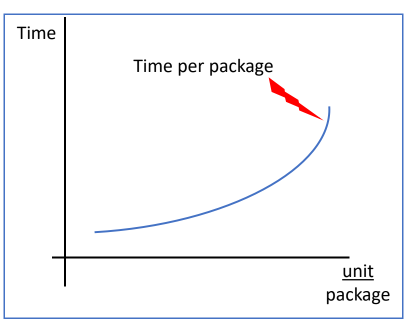

Figure 5: Time Behavior of Production Units per Package

G. Set Up

It is the time spent by the mechanic to set up the machine [14, 15, 16, 17]. For the manufacture of a garment, coverstitch, overlock, lock stitch, buttonhole and button attachment machines are used, depending on the garment model. The programming of machines is in direct relationship to the sequence of operations required for its manufacture. In a line of 14 machines, an average of one mechanic is used, since it would be too expensive to have 14 mechanics available for the setup of these machines.

The machine setup process is serial, i.e., it is performed starting from the first station, passing through the other stations until it is completed with all the machines that are sequentially distributed in the production line. In Figure 6, the equation that allows us to calculate the setup time of machines or a production line is determined. Competitiveness often finds among its main causes the lack of production integration and maintenance management [18, 19, 20].

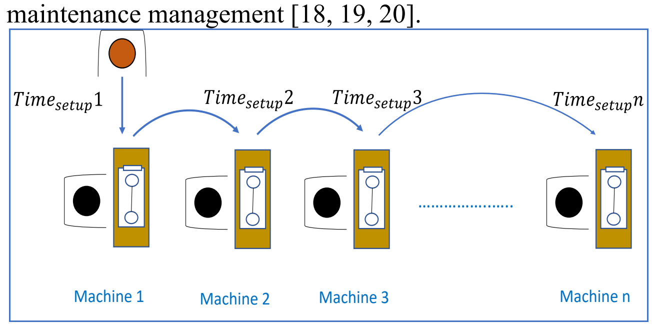

Figure 6: Setup

$$Ttotal_{setup} = \sum_{n=1}^{j} Time_{setup\ n}$$

Ttotalsetup = Total setup time of the set of machines that make up the production line.

Timesetup n= Machine setup time.

The behavior of setup times is shown in Figure 7: the more machines programmed on the production line, the longer the time required to setup them.

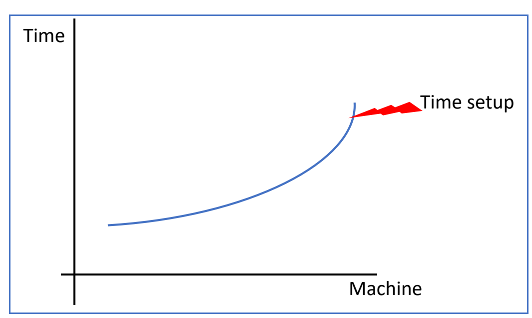

Figure 7: Setup Time Beahvior

H. Lead Time (LT)

It is the processing time [21, 22, 23, 24, 25, 26], starting when the package is distributed to the production line, from the first workstation, passing through all the required stations, complying with the characteristics indicated in the datasheet until its processing is completed. In any production process where the package passes through one activity to another, there are three periods. Figure 8 shows a graphic representation of how the LT develops and its significance.

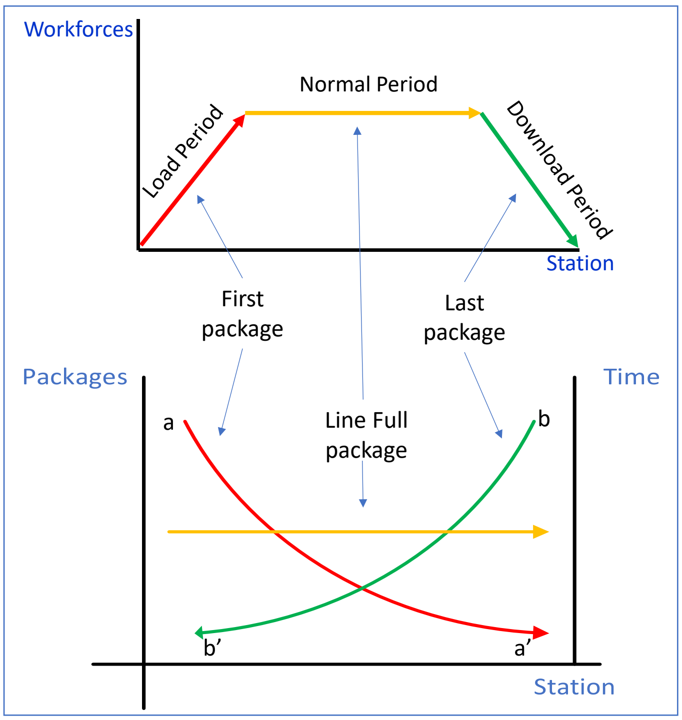

Figure 8: Lead Time Behavior

- Loading period, is the tracking of the time spent, when the first production unit or package enters the line, passing through each of the stations, respecting its operating sequence that is previously setup in the production line, until its processing is completed at the last station. Based on Figure 8, Figure 9 is determined. From (a) it can be concluded that the more packages are assigned to a station, the longer the production time. From (a') it is concluded that, as the packages processed in the first station circulate to the other stations consecutively, the number of packages for each station will be less and the number of stations with packages will be greater, and the production time for each of these stations will be less.

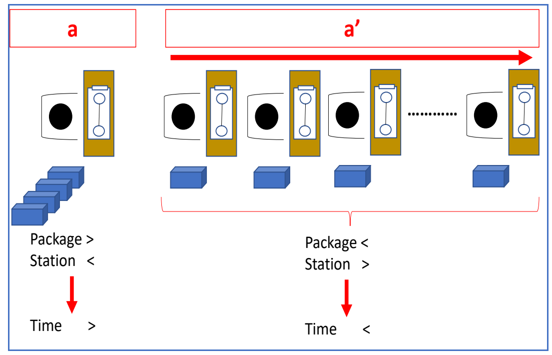

Figure 9: Loading Period

- Normal period occurs when all the stations that make up the line have their workload or packets in process passing continuously from one station to another.
- Download period is the tracking of the last package of the production order, since it enters the first station for processing and is then passed to the next station until its processing is completed, respecting its operational sequence in the production line. From Figure 8, Figure 10 was determined, and it is concluded, from (b) to (b'), that the more stations with a larger number of final packages, the longer the production time, but, as these packages circulate to the stations that follow, the number of stations tends to decrease with the number of packages, as well as their production time.

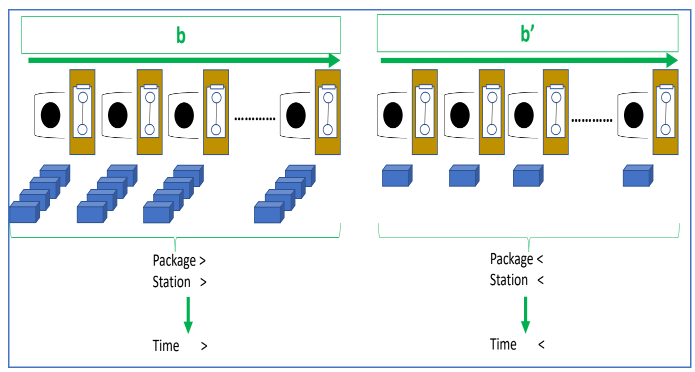

Figure 10: Download Period

From the above, we can conclude that the loading period sets the pace and speed of output of the other packages. If the line manager or supervisor does not perform a good control and optimization of the development of the activities by the sewing operator and the maintenance personnel who perform the setup, the output of the production unit will take a long time, which will increase production costs and decrease efficiency.

The independent variables to be considered to determine the LT are:

- Set up, is the time of machine setup performed by the maintenance personnel.
- Standard time, is the time it takes for the sewing operator to perform the activity.

- Production unit, is a package that enters the production line and is transferred from the first activity to the completion of all the activities.
- Unit per package, is the number of garments that make up the package.
- Machine, is the asset used by the sewing operator to make the pieces that make up a garment. These machines (lock stitch, overlock, coverstitch, etc.) are distributed in the production line consecutively and sequentially for the operating activities.
- Demand, is the quantity requested by customers.

The following data were taken into consideration for the development of this research:

General data:

Operation time: 8 hour/day, is the available operating time in which the production line must meet customer demand.

Demand: 600 unit/day, is the requirement of units (garments) to be delivered to the customer per day.

Unit / package: 16 unit/package, is the number of units in a package.

Production unit: 1 package, also called production batch. It enters the production line by package, starting from the first activity to the end of the last activity. The package is only broken when all the processing activities are completed.

And the following Table 1 shows specific data per activity:

Description	u.m.	Activity 1	Activity 2	Activity 3	Activity 4	Activity 5
Tstd (hr/paq)	(Hour*machine /unit)	0.0250	0.0225	0.0417	0.0392	0.0233
Machine #	Machine	1	1	2	2	1
Setup time #	Hour/machine	0.25	0.333	0.417	0.3	0.383

I. *System Dynamics*

The field of application of System Dynamics (SD) as a tool in the construction of management models is widely used in strategic analysis to evaluate the impact of manufacturing processes [27, 28, 29], and is carried out through causal diagrams and flowcharts of complex systems, where their temporal behavior is analyzed and modeled.

The identification of the variables that make up a certain system and their cause-effect relationship allows the decision-maker to evaluate the hypothesis and quantitatively determine its impact in a preventive manner in order to modify or optimize it according to the needs. [30, 31].

The causal diagrams and flowcharts were constructed by using the Vensim PLE plus language [32].

J. *Causal Diagram*

System Dynamics plays an important role in understanding problems and their root causes to determine consequences or alternative courses of action, and to test alternatives under different scenarios. Causality starts from the fact that every type of event originates in a cause, origin or principle.

A =========➔ B

And for an event A to be the cause of an event B the following must be fulfilled:

- That A happens before B
- Whenever A happens, B happens
- That A and B are close in space and time.

The scenario model or causal diagram in Figure 11 shows the key elements of the system and the relationships between them.

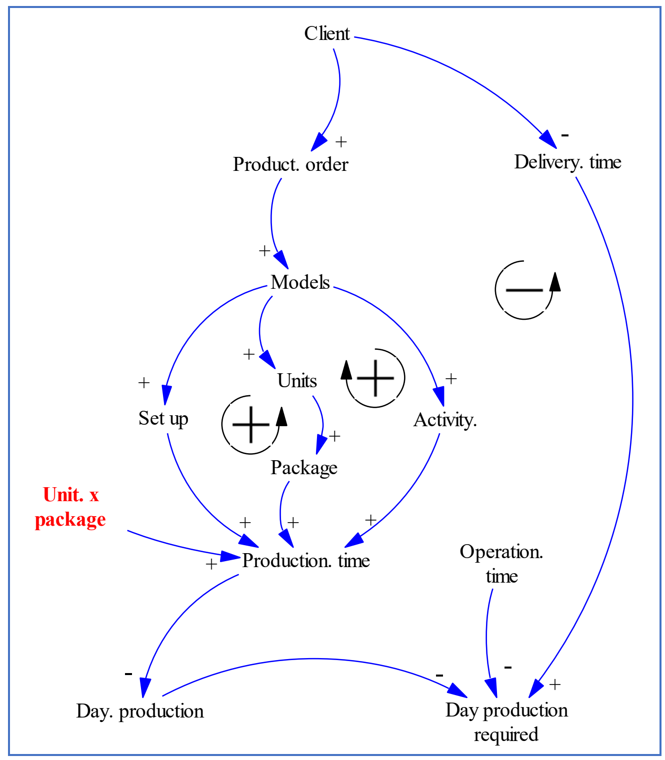

Figure 11: Causal Diagram

- The higher the number of customers, the larger the order of varied products that are required in the shortest possible time.
- The greater the variety of products, the greater the variety of models of these products.
- As the variety of models increases, the number of units and the number of activities increases, which directly affects the increase in production times.
- The greater the number of units or pieces contained in a production unit or package, the longer the execution time of the activity and the longer the production time of the line.
- The amount of production per day is inversely proportional to the production time, i.e. the longer the

production time, the lower the output quantity of the line and the longer the production times required to meet the demand.

- The more operating time available for the production line, the fewer the number of production days required.
- And the shorter the lead time requested by the customer, the fewer the days of production required.

K. Flowchart

Figure 12 shows the quantitative scenario model or flow chart; a production line with 6 activities was developed, which is made up of 21 constants and 30 auxiliary variables.

L. Dynamic Formulation

The standard time per package (1) for each activity is found by means of the direct relationship between the standard time in hours for each unit and the number of units that make up the package.

$$Tstd\ \#\left(\frac{hr*mach}{pack}\right) = Tstd\ \#\left(\frac{hr*mach}{u}\right) * \frac{unit}{package} \qquad (1)$$

Its magnitudes are:
Tstd # (hr *mach /pack); hour*machine/package
Tstd # (hr *mach /u); hour*machine /unit
Unit/package; is the number of units per package. For simulation purposes, we will consider it as 16 units.

Lead Time (LT) per activity (2) is determined by the direct relationship between the standard time of each package and the number of packages. To this, we add the direct relationship between the setup time per machine and the number of machines used for each activity.

$$LT\ activity\ \# = Tstd\ \#\left(\frac{hr*mach}{pack}\right) * ProductionUnit + SetUpTime * \#\ Machine \qquad (2)$$

Production unit; 1 package/machine
Setup time; hour/machine

The hourly production quantity (3) of each activity is the direct relationship of the number of machines per activity by the inverse relationship of the standard time per package.

$$Production\ x\ hour\ \# = \frac{1}{Tstd\ \#\left(\frac{hr*mach}{pack}\right)} * Machine\ \# \qquad (3)$$

Production x hour #; hour/package

The production per day (4) of the number of packages is determined by the direct relationship of the package production per hour to the available operating time per day.

$$Production\ Day\ \# = Production\ x\ hour\ \# * Operation\ time \qquad (4)$$

Operation time; hour/day
Production hour; package/hour
To determine the days required for a given activity (4), the inverse relationship of packages demand per day with the daily production of the activity (n) is required. To this relationship is added the inverse relationship of the unproductive time of the previous activity (n-1) (which is equivalent to the LT of the previous activity) by the operating time assigned to the activity (n) (5).

$$Days\ required = \frac{Demand(paq)}{Production\ Day_n\#} + \frac{Downtime_{n-1}}{Operation\ time_n} \qquad (4)$$

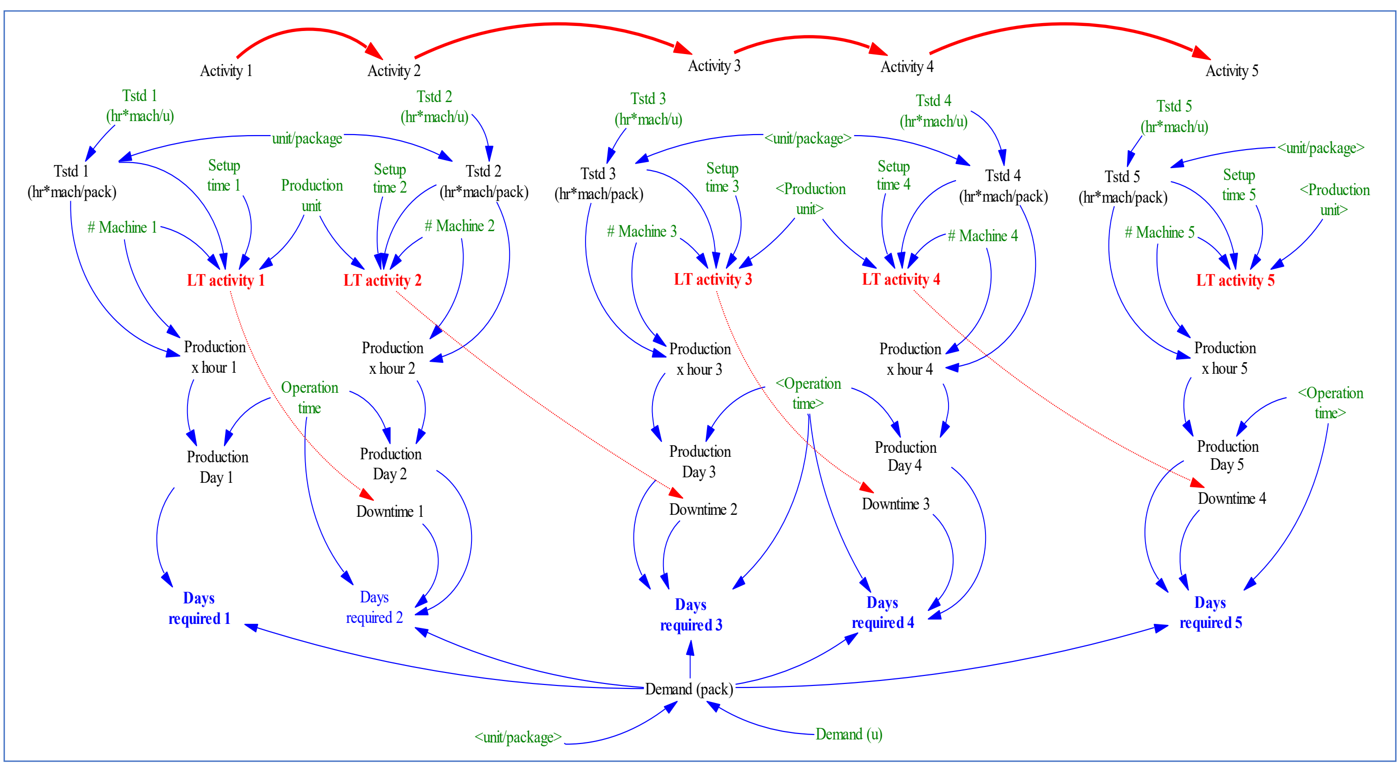

Figure 12: Flowchart

Where:

$$LT\ activity_{n-1} = Downtime_{n-1} \quad (5)$$

III. Results

Figure 13 shows that for a production unit or package formed by 40 units pessimistically, the behavior of the LT processing time increases cumulatively. This is due to the fact that the stations that follow it must wait for the previous station to finish processing its package. This leads to an increase in unproductive times, resulting in a final lead time to the customer of 1.18 days for this production of 310 units, that is, 9.44 hours, when the available operating time is 8 hours.

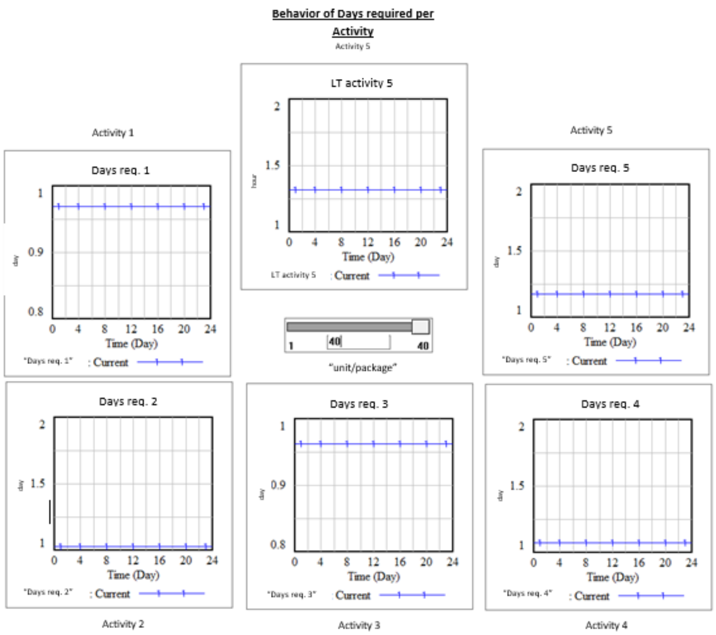

Figure 13: LT behavior for 40 units per package

In Figure 14, for a package consisting of 20 units in normal conditions of line operation, the days required for delivery to the customer was 1.08 days, i.e. 8.64 hours, not meeting the time requested by the customer.

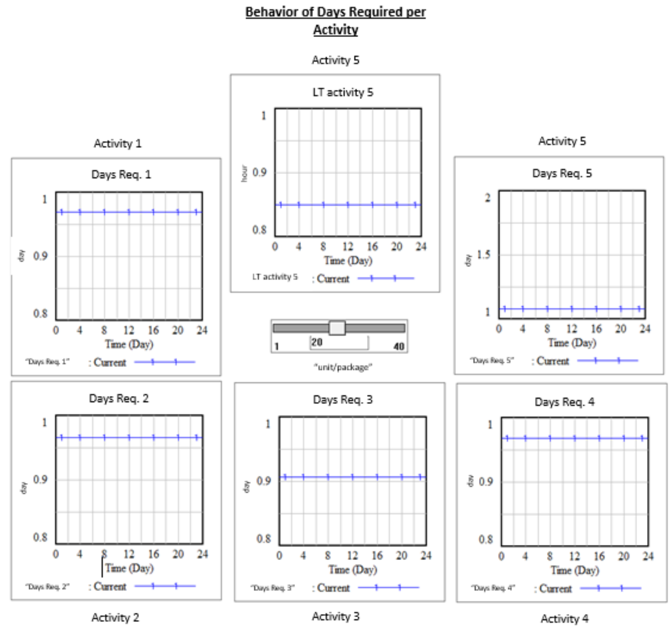

Figure 14: LT behavior for 20 units per package

But if the production line worked with packages of less than 5 units as shown in Figure 15 or by breaking the package, i.e. per unit, it would achieve the goal of delivering 310 units to the customer in one day.

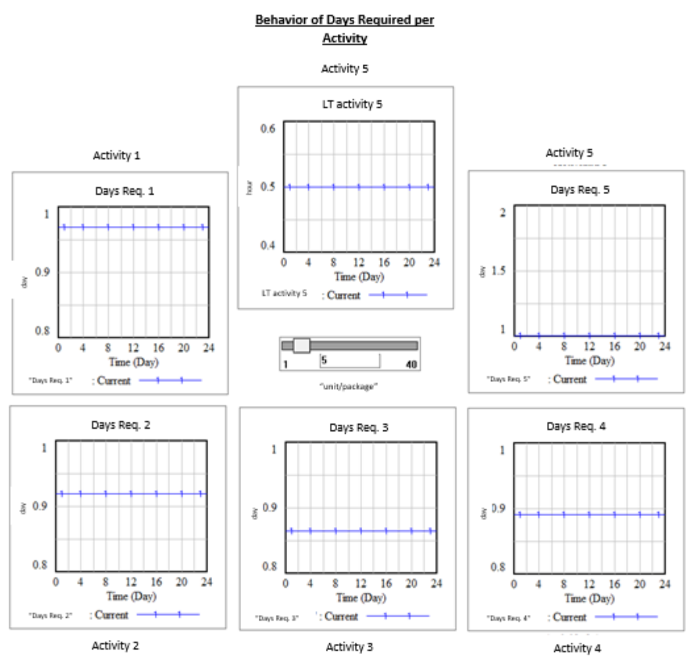

Figure 15: LT behavior for less than 5 units per package.

IV. Discussion

To determine the processing time or LT of the production units that marks the rate of progress of the production areas in the manufacturing sector, it is important to analyze and control from the loading period as well as the cause-and-effect relationship of the variables, as exposed in this research, but this is not disclosed in the research carried out by:

- Dias [33] presents a cooperative strategy between seller and buyer with a constant demand, formulating it as a mixed-integer, nonlinear programming problem to determine the minimum cost considering the following decision variables: reorder point, size of the batch for delivery, number of deliveries and delivery time thresholds.
- Li [34] in his research provides information on practical crop yield forecasting and the understanding of the yield response. It determines the optimum lead time for yield forecasting.
- Kouki [35] presents in his research, heuristically, the effect of shelf life and lead time variability on the system cost and the optimal base stock level.

There is research that validates that the shorter the delivery time of products to the customer, the lower the costs, such as:

- Li [36] explores and quantifies the benefits of lead time reduction. His analytical results show that inventory cost is a strictly increasing concave function of both lead time and its variation.

V. Conclusions

A smart organization learns from everything that happens to it, listens and acts according to what its customers want and, under the filter of its strategy, acts by quickly modifying its tactics to adapt to its ever-changing environment.

The conceptualization of scenario models by the organization allowed to visualize at a macro level the system in which the manufacturing process is developed for the variety of garment models, observing through experimentation the interaction of cause and effect between variables and constants.

The ordering of variables and constants made it possible to quickly identify, simulate and evaluate which were the limiting variables, due to their causality.

It was quantitatively demonstrated by means of the flow chart that the loading period, with an ever-decreasing setup of production units, has a direct influence on the reduction of production lead times to customers, without neglecting the quality of its processing in each activity.

References

[1] V. Quezada, J. Seck, J. Quezada and A. Cuatepotzo, “Multiple system of production optimized by PSO”, *Ingeniería Investigación y Tecnología*, volume XXI (number 1), January-March 2020, p.2.

[2] G. Lanza, S. Treber, “Transparency increase in global production networks based on multi-method simulation and metamodeling techniques”, *CIRP Annals - Manufacturing Technology* 68 (2019), p 439.

[3] M. Dittrich, S. Fohlmeister, “Cooperative multi-agent system for production control using reinforcement learning”, *CIRP Annals - Manufacturing Technology* 00 (2020), p. 1.

[4] P. Fang, et all, “Data analytics-enable production visibility for Cyber-Physical Production Systems”, *Journal of Manufacturing Systems* 57 (2020), p. 242.

[5] D. Tsutsumi et all., “Joint optimization of product tolerance design, process plan, and production plan in high-precision multi-product assembly”, *Journal of Manufacturing Systems* 54 (2020), , p.

[6] M. Flores, D. Flores, B. Meneses, “Dynamics of Organizational Change”, *(IJACSA) International Journal of Advanced Computer Science and Applications*, Vol. 11, No. 10, 2020, p. 482.

[7] J. Lin, L. Zhou, V. Spiegler, M. Naim, A. Syntetos, “Push or Pull? The impact of ordering policy choice on the dynamics of a hybrid closed-loop supply chain”, *European Journal of Operational Research*, November 14, 2021, p. 1.

[8] E. Salazar, M. Riquelme, “Lot sizing and scheduling of multi-products on a single machine with sequence-dependent setup times”, *Ingeniería Investigación y Tecnología*, volume XXII (number 3), 2021, p.2.

[9] W. Chen, “Intelligent manufacturing production line data monitoring system for industrial internet of things”, *Computer Communications* 151 (2020) 31–41, p. 32.

[10] S Rymaszewski, J. Watrobski, A. Karczmarczyk, “Identification of reference multi criteria domain model – Production line optimization case study”, *Procedia Computer Science* 176 (2020) 3794–3801, p. 3794.

[11] M. Colledani, A. Angius, “Production quality performance of manufacturing systems with in-line product traceability and rework”, *CIRP Annals - Manufacturing Technology* 00 (2020) 14, p. 1.

[12] N. Papakostas, J. O’connor, V. Hargaden, “Integrated simulation-based facility layout and complex production line design under uncertainty”, *CIRP Annals - Manufacturing Technology* xxx (2018), p.1.

[13] A. Andrade, C. Del Rio and D. Alvear, “A Study on Time and Motion to Increase the Efficiency of a Shoe Manufacturing Company”, *Información Tecnológica*, Vol. 30(3), 83-94 (2019), p.84.

[14] H. Hissashi, M. Seido, J. Gupta, “Integrating preventive maintenance activities to the no-wait flow shop scheduling problem with dependent-sequence setup times and makespan minimization”, *Computers & Industrial Engineering* 135 (2019) 79–104, p. 79.

[15] C. Yang, P. Pourhejazy, K. Ching, Y. Hsiu, “New benchmark algorithms for No-wait Flowshop Group Scheduling Problem with Sequence-Dependent Setup Times”, *Applied Soft Computing* 111 (2021) 107705, p. 1.

[16] E. Molee, R. Sadeghian, P. Fattahi, “Minimizing maximum tardiness on a single machine with family setup times and machine disruption”, *Computers and Operations Research* 129 (2021) 105231, p. 1.

[17] C. Chi, H. Hua, N. Aini, “Production decision making considering dual material types and setup time uncertainty”, *Applied Mathematical Modelling* 96 (2021) 751–765, p. 752.

[18] R. Diaz, E. De la Paz, D. Delgado, “Algorithm for integrated programming of production andpreventive maintenance on identical parallel machines”, *Ingeniería Industrial*, Vol. XL, No. 3, September-December 2019, p. 261.

[19] R. Marrero, J. Vilalta, E. Martinez, “Model diagnostic–maintenance planning and control”, *Ingeniería Industrial*, Vol. XL, No. 2, May-August 2019, p. 149.

[20] A. Enriques, E. Muñoz, A. Concepcion, et all., “Maintenance actions supporting a biotechnological production enterprise”, *Ingeniería Mecánica*. Vol. 22. No. 1, January-April, 2019, p. 1.

[21] I. Wennman, E. Carlstrom, B. Fridlund, H. Wijk, “Actions taken affecting lead time in the care pathway for low-priority patients with a suspected stroke: A critical incident study”, *International Emergency Nursing* 60 (2022)101105, p. 2.

[22] B. Koli, S. Bhuniya, B. Sarkar, “Involvement of controllable lead time and variable demand for a smart manufacturing system under a supply chain management”, *Expert Systems With Applications* 184 (2021) 115464, p. 1.

[23] Y. Zhai, T. Chen, “Lead-time quotation and hedging coordination in make-to-order supply chain”, *European Journal of Operational Research,* August 23, 2021, p. 1.

[24] S. Haeussler, M. Stefan, M. Schneckenreither, A. Onay, “The lead time updating trap: Analyzing human behavior in capacitated supply chains”, *International Journal of Production Economics* 234 (2021) 108034, p.1.

[25]J. Bender, J. Ovtcharova, “Prototyping Machine-Learning-Supported Lead Time Prediction Using AutoML”, *Procedia Computer Science* 180 (2021) 649-655, p. 650.
[26]M. Zied, Y. Dai, Q. Li, A. Syntetos, X. Wang, Forecasting of lead-time demand variance: Implications for safety stock calculations, European Journal of Operational Research May 26, 2021, p. 1.
[27]L. Rodriguez, J. Loyo, M. Lopez and J. Gonzales, “Dynamic simulation of a back-feeded production system”, *Ingeniería Industrial*, Vol. XL/No. 2, 2019, p. 172.
[28]K. Perez, D. Ibarra, M. Ballen, “Modelling biodiesel production from microalgae, using industrial wastewater as a growth medium”, *Revista chilena de ingeniería*, vol. 28 Nº 4, 2020, pp. 744-754, p. 746.
[29]J. Delgado, “Modelo dinámico de la pandemia de COVID-19 [Dynamic model of COVID19 pandemic]”, *Sanid. mil.* 2021; 77 (1), p. 9.
[30]W. Bonela, G. Mattos, “System Dynamics for Sustainable Transportation Policies: A Systematic Literature Review”, *Revista Brasileira de Gestão Urbana*, 2021, 13, p. 2.
[31]L. Da Silva, S. Barbalho, R. Augusto, “A bibliometric-qualitative study about the use of System Dynamics in the areas of Project and Program Management”, *Gestão & Produção*, 28(4), e5770, 2021 p. 2.
[32]J. Diaz, E. Guerra, H. Neira, J. Garcia, L. Londoño, A. Valle, “Analysis of system dynamics in Vensim software”, *Revista Espacios,* Vol. 40 (Nº 38) Year 2019, p. 20.
[33]M. Dias, B. Sraker, “Optimizing a supply chain problem with nonlinear penalty costs for early and late delivery under generalized lead time distribution”, *Computers & Industrial Engineering,* Volume 160, October 2021, 107536, p. 3.
[34]L. Li, B. Wang, P. Feng, H. Wang, Q. He, Y. Wang, D. Liu, Y. Li, J. He, H. Feng, G. Yang, Q. Yu, “Crop yield forecasting and associated optimum lead time analysis based onmulti-source environmental data across China”, *Agricultural and Forest Meteorology*, 308-309 (2021) 108558, p. 11.
[35]C. Kouki, B. Legros, M. Zied, O. Jouini, “Analysis of base-stock perishable inventory systems with general lifetime and lead-time”, *European Journal of Operational Research* Volume 287, Issue 3, 16 December 2020, Pages 901-915, p. 32.
[36]X. Li, “Valuing lead-time and its variance in batch-ordering inventory policies”, *International Journal of Production Economics* 228 (2020) 107731, p. 5.