Production time estimation on a ConWIP line that includes scrap and rework

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Abstract

Taking productivity as the main objective of an industry, the following research proposes a new parameterization based on the adaptive ConWIP model, which exposes the inexistence of waste and reprocessing in a production line that works under said system. For this reason, this proposal is applied to an environment in which the occurrence of such eventualities is included. To evaluate the proposed parameterization, a simulation is carried out in order to observe the variations generated from the results obtained by comparing the original model and the one currently exposed. This is done in order to take a correct decision regarding the optimal amount of WIP maximum that a production line must handle. By contrasting the adaptive ConWIP model and the proposed model, it resulted in a statistically significant difference between the means of the data populations involved in the research. In addition, through an analysis carried out on the populations, it is determined that there is no benefit when considering scrap and rework in the amount of maximum WIP obtained, in relation to the cost of maintaining inventory and the number of units produced.

Keywords
ConWIP, WIP, Production, Push System, Pull System, Scrap, Reprocess, Throughput.

1. Introduction
In every industry there is a primary focus on the interest in achieving customer satisfaction, with respect to the products purchased from it. For this reason, the power and control systems seek to be efficient in reducing work in process, costs and delivery times (Belisário et al. 2015).
As a result of the above, this research will address the ConWIP feeding system, introduced by Hopp and Sperman in 1990, which is associated with the control of a production line as an alternative method of Kanban (Barreto 2015).
The acronym of ConWIP has the following meaning: "Con" from "Constant" that is to say constant and "WIP" referring to the term "Work in progress" (Pérez 2018).
This system is used in order to maintain the level of inventories in process within a constant value, controlling the amount of material that enters the system. Likewise, by means of this production control, it is intended to achieve the

no need to have a warehouse for the finished product, thus reducing the high inventory storage and maintenance costs (Pérez 2018).
In addition, another important factor on which ConWIP focuses, corresponds to the reduction of costs related to inventory maintenance and in the same way, it is linked to the time that the raw material or material occupies within a line of production.
An essential aspect to assess in decision-making regarding the implementation of a production system such as the one in this study, corresponds to the maximum use of an organization's resources, in order to avoid idle times in a production line, preventing the delay in the completion, delivery and especially the waste of these inputs (Pérez 2018)..
On the other hand, these systems are implemented in organizations or industries that require effective use of the facilities, considering bottlenecks in operations.
In this article, a study of the system is addressed ConWIP power supply including various parameters, which are not contemplated in a specific model. The interest of this research is given by the need to know the influence of certain factors present in organizations, in order to obtain a more realistic perspective on the capacities that these should have for the satisfactory fulfillment of their work.
Ultimately, the structure of the article is presented, which is organized as follows: in section II a compilation of different literatures about the system in question is made. In section III, a proposal for the topic and the justification of the criticism to be developed are established. In section IV, the statement of the problem is presented, therefore, in the continuous section, a simulation is developed in order to verify the applicability of the proposed criticism. Finally, conclusions are drawn on the validation carried out and future lines of research are detailed.

2. Literature Review

A. Feeding systems

The feeding or production systems are those with which the movement of the raw material is explained, specifically the way in which it enters the production line. There are two main elements, which correspond to physical flows and control strategies or information flows. In relation to the physical aspects, these are made up of the resources that the production line has, for which, the control strategies allow the correct use of the resources mentioned (Flórez et al. 2016).
Taking into consideration what was previously analyzed, these control strategies are divided into Pull and Push or a combination of these.
By means of a production master plan, information about demand forecasts is stored and it is from this that the Push system activates its respective production (Núñez et al. 2015). A factor to consider when operating under this system, in addition to prior knowledge of the demand, corresponds to the time it takes for the raw material to become a finished product or a part of it (Jiménez et a. 2019).
On the other hand, Pull type feeding systems are based around the production of an item at the time the customer needs it and in the quantity requested. For this, this control strategy uses only the required material and therefore minimizes overproduction (Jiménez et a. 2019).
From the above, the ConWIP is classified as a hybrid power system. This corresponds to a system in which it works under the Push production criterion, because it is produced without having an established order, until reaching a maximum level of the WIP and once this is reached, production is stopped. At this point, the WIP level begins to decrease. To start production again, the ConWIP system becomes a Pull type feed, since, from a reorder point, a new production authorization is generated for the stations that feed the line (Amán 2017).

B. WIP

The term WIP is known in a large number of fields and mainly in the development of production. This concept refers to the work that is in process. It corresponds to the matter that is being changed or altered by external factors (Zhou and Rose 2019).
Similarly, in the implementation of this system, one of the main factors to reach the level of the WIP and therefore remain in it, is the number of cards. Knowing the available quantity of these is a challenge for engineering, since it is with it that it is determined if the production objective is achieved and therefore, the early or on-time delivery of the product to the respective client (Pérez 2018).
Some important considerations about WIP is that it manages to reduce the difference between the various cycle times. For this reason, there is a decrease in the variation of costs due to inventory maintenance (Pérez 2018).
One of the aspects to take into account in the establishment of the WIP corresponds to the fact that it must be changed regularly, depending on the variations in demand and programmed production. It is for this reason that the ConWIP system uses this limitation to create a stable capacity scenario and thus comply with the budget (Zhou and Rose 2019).

C. ConWIP

The ConWIP is a production control system that considers certain peculiarities, one of them is that it is defined as a production line that consists of a single route. It does not present deviations towards other different lines and assumes that the jobs carried out are identical (Barreto 2015).

Another aspect corresponds to the fact that the product is moved in containers, so that there is the same amount of work in each of them. Then, at the beginning of the line to these containers a card is attached, which travels with the work throughout its entire manufacturing time, until reaching the final point at which the product is dispatched and delivered to the customer (Hoose et al. 2016).

Once this happens, the card is released and sent to the entrance or beginning of the line, where it will proceed to place it in the next job to be processed. No container can start its process, if it does not have one card that identifies or authorizes it (Belisário et al. 2015).

In addition, it is important to mention that the bottleneck is not defined in a ConWIP system. Therefore, its purpose corresponds to maintaining a constant amount of WIP, in order to adapt to the variation in the position of said bottle neck. This way, each operation is able to respond to a certain eventuality. In addition to the above, to apply this system in a production line, it must be characterized by working close to its capacity (Choque 2015).

Likewise, to ensure the effectiveness of the system in a ConWIP production line, a routing is required and therefore, as far as possible, a homogeneity in it (Nick 2019).

D. Parameterization

As a result of the theoretical elements described above, we proceed to propose the parameterization corresponding to the model in question. It is important to note that this system has the level of WIP as one of the determining parameters for its operation, which is based on Little's Law (Samir 2016), the formulation is found in equation (1).

$$WIP = TH * Makespan \tag{1}$$

Where:

Makespan = Cycle time.

As observed in the previous equation, this law is influenced by the TH (throughput) or the percentage yield of the production line. For which, Hopp and Spearman delimited the TH as a function of the number of cards, this is found in equations (2) y (3) (Barreto 2015).

$$TH(w) = \frac{w * g}{w + W_0 - 1} \tag{2}$$

$$W_0 = g * T_0 \tag{3}$$

Where:

w = number of cards.

g = bottleneck rate (per minute).

W_0 = critical level of WIP.

T_0 = sum of average station processing times (variability or any interruption in the system is not taken into account).

It should be noted that the bottleneck is the station that slows down the system, causing the production process to slow down and have a higher utilization percentage (Pérez 2018).

E. Applications in production

The ConWIP system is used mostly in organizations who's production lines operate close to their capacity (Choque 2015). This system is applicable to multiple production environments, which can work both based on the inventory level (Pull), and on MPS decisions (Production Master Plan) for item needs (Push) (Pérez 2018).

The ConWIP involves a series of strategic factors that promote an active participation in the market and a search for various benefits for an organization. As a result of the implementation of various aspects, it is possible to generate some benefits from the implementation of ConWIP in a production line, which correspond to:

- Like the Pull type feeding system, the ConWIP, handles reduced inventory levels and therefore, minimizes its cost (Pérez 2018).
- Due to its mode of operation, this feeding system avoids the accumulation of final inventories, since it authorizes production when there is an established demand for the product (Pérez 2018).
- In various cases, ConWIP uses Material Requirements Planning (MRP) as an information system, in order to adapt production to the feeding system (Pull and Push) (Pérez 2018).
- One of the benefits of the implementation of ConWIP on the line, is because it controls throughput, maintaining a constant WIP (Amán 2017).

Now, regarding the disadvantages of using a ConWIP system, it is worth mentioning its slow response to changes in demand, since this change leads to alterations in the signals of the system. It also affects the percentage of station utilization, since it makes it the lowest in the system, causing the organization to have an overload due to the simulation software that must be obtained in order to achieve the optimal system configurations. Lastly, the ConWIP requires that the organization that implements it assumes a risk on the part of human support to correctly reproduce the sequence of jobs (Pérez 2018).

3. Subject proposal and justification

In general terms, the adaptive ConWIP feeding model or system is based on the idea of adjusting the state in which the production of a line is executed. Specifically, such a system focuses on measuring WIP and performance. The latter is of utmost importance since, through performance, the objective is to verify and control whether the levels of this in the line are below or above the limit (Belisário 2015).

As mentioned, the main objective of ConWIP is to control the total amount of work in the production line, keeping it constant (Lamouri 2016). In addition, one of the mandatory parameters that a ConWIP system must comply with corresponds to the limit of the WIP level. This term can be found in different locations on a line depending on the order sequence. For this reason, the jobs that are being processed or those that are waiting to be processed must always be constant to be able to continue calling the system, ConWIP (Frazee and Standrige 2016).

The assumptions of the feeding system are (Belisário 2015):

- There is an infinite supply of blanks.
- There is only one unit in each container.
- A single standard product is produced.
- There is no waste and no breakdown of the machine.
- A unit of raw material must be processed to satisfy a unit of demand.
- The discipline of "first come, first used" is used to process parts.
- Transportation times are negligible.
- Demands arrive according to a variable rate Poisson process λt.

Taking into account the previous assumptions, we work on a critique that varies one of these, which is detailed as: "There is no waste or there is no breakdown in the machine". However, this has the possibility of being variable since, in relation to scrap, a company is directly affected in the process flow due to the existence of productivity limitations. For example, overproduction, transport of materials, among others (León et al. 2017).

In addition, reprocessing is an unavoidable event in most organizations. It is characterized by redoing one or more processes in order to repair a defect in a product unit, which leads to a reduction in work capacity and therefore in an increase in unproductive hours, directly affecting the profitability of the company (Hernández et al 2018).

As a result of all the information collected previously, it is proposed to contemplate a ConWIP system, which contains in its parameterization, the variations that scrap and rework factors could generate in a production. This, in order to know the possible real panorama that an organization can face in certain eventualities.

4. Problem statement

The approach to the present problem arises as a response to the need for the analysis of the previous criticism, based on a company in charge of textile production that works by means of an adaptive ConWIP feeding system. A production line is considered which has 5 machines, of which 4 are considered within the ConWIP system, for the elaboration of a single product under a discrete production. The purpose of this analysis is to observe the changes that a ConWIP production system would have when including a percentage of scrap and a probability of reprocessing in its production. The percentage of scrap contemplated in each machine of the production line studied is considered individually, this because, in a real organization, all the machines generate different amounts of waste in terms of the relationship between the total number of defects in each one and the total number of units produced (Álvarez 2019). Equations (4) and (5) present the way to calculate the scrap percentage for each machine contemplated.

$$\%scrap = 1 - e^{-DPU} \tag{4}$$

Where:

$$DPU = \frac{total\ of\ defects\ of\ the\ machine\ n}{total\ of\ units\ of\ the\ machine\ n} \tag{5}$$

In relation to the existing reprocessing in the production line, this will be considered by means of the rework analysis based on the use of Markov absorbent chains. For which the probability of occurrence in terms of said event is detailed, in order to obtain an adjusted cycle time. This will be equivalent to the Makespan where both the reprocessing and scrap of each machine will be included. Now, knowing the new parameters that the WIP level will contemplate in a production line under the ConWIP feeding system in the mentioned textile industry, the new formula that will be used corresponds to equations (6) and (7) shown below:

$$ConWIP = \left(\frac{w*g}{(g*T_0)+w-1}\right)*Makespan \quad (6)$$

Where:

$$w = \left(D*\frac{Makespan}{T.available}\right) \quad (7)$$

Finally, it is important to mention the guidelines on which the simulation is based, which are detailed below:

- Two independent simulations are run, one for the original ConWIP and one for the proposed model.
- A constant demand is considered for both models.
- Processing time per machine is variable.
- Scrap and rework is variable for each machine.

5. Validation

This section shows the results obtained through the simulation carried out. From a database, a model is created in simulation software. In relation to the above, a scenario is proposed in which all the machines contemplate a certain percentage of waste, however, the second and fourth machines contemplate both waste and reprocessing. With the changes made to the original formula explained in section IV, the calculation is executed for the new level of ConWIP in the production line, which is 179 units. Opposed to the original ConWIP that corresponds to 163 units. Knowing the previous data, we proceed to carry out the simulations with a size of 30 samples. In each sample, the scrap and reprocessing are varied, keeping the ConWIP values constant, both for the original parameterization and for the proposal. An extract of the results obtained in the previous simulation of the processing time, are observed in Table I.

Table I: Summary of data obtained

Sample	Original ConWIP (min)	ConWip proposed (min)
1	3991.85	4054.85
2	3907.85	4012.85
3	4028.85	4068.85
4	4047.85	4089.85
5	3935.85	4033.85

As a way of comparison, it is observed in Figure 1, that the processing time of the original ConWIP is less than the processing time of the new proposed model. In addition, it is possible to observe that as the amount of maximum WIP increases, the processing time in the production line increases.

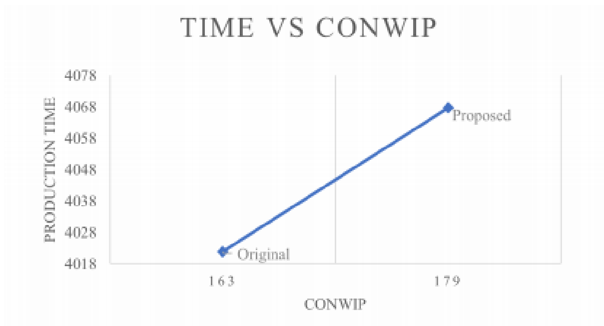

Figure I. Relationship between processing times

Once the simulation has been carried out, we proceed to check if the results obtained in it present a normal distribution, with a confidence level of 0.95. As shown in Figure 2 and in Figure 3 both the data obtained from the original ConWIP and the data from the proposed ConWIP are normal, since their p value is greater than the significance of 0.05.

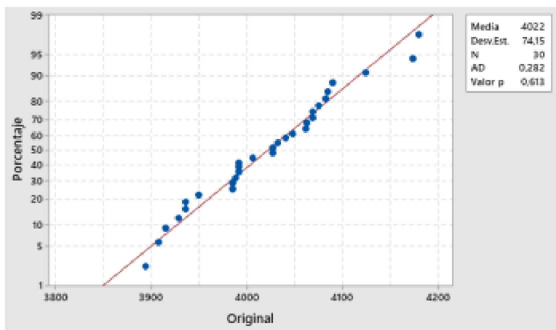

Figure II. Graphic of original ConWIP normality test

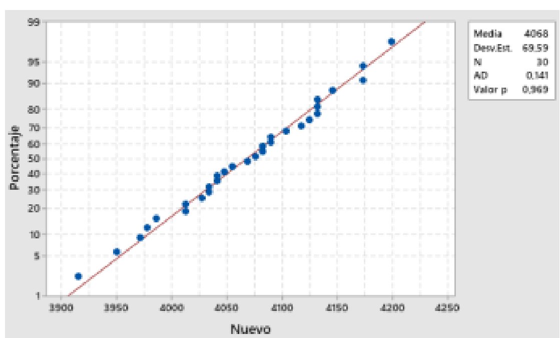

Figure III. Graphic of Proposed ConWIP normality test

Once it is certain that the analyzed data sets follow a normal distribution, a paired T test is carried out. This to identify differences between the means of the data sets involved and determine if the formula proposed in this research really has a significant effect on the production line (Myers et al. 2012). Based on this test, the following hypotheses are established:

- Null hypothesis H_0: difference μ = 0
- Alternate hypothesis H1: difference μ 6= 0

According to the paired T test carried out with a confidence level of 0.95 to the before mentioned data sets, which correspond to processing times obtained from both the model proposed in the research and the basic parameterization of ConWIP. It is possible to identify that, for this test, the p-value obtained is less than the significance level. In accordance with this finding, it is determined that there is a statistically significant difference between the means of both data sets and therefore, the null hypothesis is rejected.

6. Conclusion

In conclusion, when analyzing the previous parameterizations, it is shown that the processing times obtained with the original model are less than those obtained with the proposed one. Therefore, it is determined that there is no positive impact when considering scrap and reprocessing in the amount of WIP. This is because, when making a comparison between both parameterizations, considering a specific time, it is possible to produce a greater number of units with the original configuration in contrast to the proposed one. It is important to mention that time is an indicator of the agility of the production line, therefore, the fact that this is lower implies greater flexibility to face possible changes required by the client.

In relation to the value obtained from the level of product in process, it is determined that this increases in the proposed model, which implies a higher cost in maintaining inventory and, consequently, a decrease in the organization's income.

Also, as it is a product in process, the cash liquidity is not recovered promptly. This leads to limitations in the start of production, the acquisition of new materials or other activity.

As a recommendation, the use of one or another parameterization will depend on the type of company, the characteristics of the product, the number of people and the degree of collaboration. Considering that what is sought in a company is to define the appropriate product in process that allows reaching the best levels of productivity.

From the results obtained, possible future investigations are identified, corresponding to the analysis of the effects, in relation to the machine breakdown times and, consequently, the amount of desirable WIP to adapt to these new circumstances.

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