Assessment of the Suitability of Reconfigurable Design Through Simulation and Decision Trees

Ricardo I. Ramirez Guzmán, Mario L. Chew Hernández, Mtro. L. Viveros Rosas, Ricardo R. Figueroa

Abstract—Positioning of the equipment of a manufacturing company is done foreseeing that it will remain fixed for a long time. This is because changes in the plant layout are thought to be costly, as they involve redesigning equipment support services, developing new foundations, using heavy machinery to move equipment, and causing non-productive time at the plant. However, the increased competition due to globalization, lead us to consider the alternative of making modifications to the layout more frequently to improve productivity. Changing the position of the equipment can be facilitated by specifying smaller mobile process equipment or by anticipating the availability of services at different points in the workshop and the existence of cranes or other means of transportation [2]. These forecasts, result in a greater investment in elements that, at least initially, do not generate any profit.

This work shows the evaluation of the feasibility of modifying the positions of the equipment when there are variations in the probability distribution in production speeds. This evaluation is carried out using decision trees and process simulation. The case study addressed consists of a generic production line with serial workstations. Jobs arrive at the first computer and join their product on hold if space is available, otherwise the job is lost. In the same way, the product on hold of the other teams are limited in size, and when a product on hold is full, the team behind stops until there is space available. Due to the use, the speeds of the equipment are changing with respect to the ones they had when new: the process times are increasing and / or becoming more variable. To improve productivity under the new process speeds, the space between the equipment can be modified, however, during this change, production must be suspended.

This work shows how, by simulating processes and decision trees, it is possible to determine the ranges of values of the suspension time and the cost of transport for which it is convenient to make changes in the spacing of the equipment.

Index Terms—Layout, Manufactures, Design, Efficiency, Equipment, Reconfigurable.

I. INTRODUCTION

The design of the layout of a manufacturing company is carried out with the intention that it be maintained for a minimum of three years of operation since the changes in the plant are costly, as they may involve the redesign of the support services for the equipment, elaboration of new foundations, use of heavy machinery for the movement of equipment and non-productive time in the plant [1].

However, plant layout can be designed with some degree easy to modify (reconfigurable): Smaller, more mobile process equipment, redundant production lines, availability of services at different points in the shop, and / or existence of cranes or other means of moving equipment.

These forecasts lead to a more expensive and less efficient plant distribution.

II. LAYOUT

Design is a very important topic when talking about a company, you will find the disposition or the consistent design in the location of the different sectors or departments in a factory or service facilities, as well as the equipment within them [3].

The purpose pursued with the design analysis is an optimal allocation of the plant space based on the resources used. The location of resources and their interaction is a decision of vital importance for the success of the Production System.

The space becomes an important analysis of the production processes. The before mention covers every part of the production process, from the moment the raw materials are received, to the shipment of the finished product. This process must be efficient and economical.

The benefits when is flexible design is that it can be efficiently practical, optimizing space improves station flow and increases productivity.

III. FRAMEWORK

A company that manufactures Product 1 (P1), with a production sequence (S1) of M1 | M2 | M3 is considered.

The design demand of the machines is QD units per unit of time. Efficiency (in %) depends on its operating point (q), expressed as% of design capacity. This efficiency can refer to the cost or time required to process each part. (fig.1)

![Fig. 1. Layout 1 and 2 plant distributions are designed for a Q flow of product P1](image-url)

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The purchase of smaller equipment is shown in Layout 2, of equipment with half the capacity of Q.

Given the economies of scale, the cost of purchase and installation (CC&I), labor (CMO) and material handling (CMM) of Layout 2 is greater than that of Layout 1. By means of simulation, the advantages of Layout will be evaluated with respect to Layout 1, regarding the following dimensions.

A. Robustness with regard to breakdowns and departure from the point of operation of the design capacity

Design 2 is more robust compared to machine breakdowns. The convenience of maintaining Layout 2 instead of 1 due to this quality depends on the probability distributions of the time between decompositions (\(\Delta t_D\)) and the repair time (\(\Delta t_R\)), as well as the consequence of not having production or seeing it diminished (which can be the loss of customers for not having enough inventory).

Likewise, if the operating point falls below the design point, the efficiency loss of Layout 2 is less than that of Layout 1, since in the former, at least one machine set can be maintained at its capacity of design.

B. Robustness with respect to changes in the composition of the production mix.

Consider that the design is for P1, but it may be that, due to changes in customer demand or tastes, in the near future a second product P2, with operation sequence M1 | M3 | M2, must be manufactured in the same plant. Of the total demand Q, the quantity (\(\alpha Q\)) corresponds to P1 and the quantity (1-\(\alpha\)) Q corresponds to P2. Under this scenario, the operation of the Layouts is illustrated below.

C. Adjustments in plant space for local work-in-process warehouses.

When a work-in-progress area of a machine fills up, the operation of the back machine stops. When designing the design, this is done based on the probability distribution of the speed (\(\Delta t_i\)) of new machines. Productivity under this scheme is Q pieces per day.

Machine time may be more variable than expected due to factors ranging from aging of the machine to the skill of the operators. Assuming machine 2 ages faster than machine 1 or 3, the working space in this machine’s process will be completely full and machine 1 should be subject to multiple stop / start operations. Productivity, with this probability distribution at the speed of machine 2, is Q’.

One way to increase productivity is to use area “A” as a temporary warehouse for the pieces that do not fit in the WIP, however, it will be necessary to consider the transit times from this area to the tail of machine 2. When both “A” and WIP, 2 are full, machine 1 stops. The productivity observed with this configuration is Q”. (fig.8)

Different values of area A would provide different productivity. Finally, by moving the equipment you can adjust the work area in the process of machine 2, as shown in the figure below (fig.9). Under this scheme, productivity is Q’’. The increase in productivity due to the adjustment must be balanced with the cost implied by the interruption of advantage if there is a necessary tooling change between products P1 and P2.

If the \(\alpha = 0.5\) condition is maintained for a long time, design 2 can be reconfigured as.

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production to carry out the movements.

Fig. 9. Adjusted working area in machine process 2

IV. CASE STUDY

A plant with three machines/processes (M1, M2, M3) is considered, the maximum sizes of the tails of these processes are denoted as N\text{MAX}, i (i = 1-3). The company can receive two types of jobs (Piece), called piece type 1 and type 2. The processing sequence for type 1 parts is M1→M2→M3 and for type 2 M2→M3→M1.

Upon arrival, Type 1 parts will try to join the tail of the M1 machine, and Type 2 parts to that of the M2 machine. If, on arrival, a part finds the tail of the machine to which it must be allocated, it has just processed does not have space to receive it.

Initially, machines can only order following the order of the processing sequence for type 1 parts is M1→M2→M3 and for type 2 M2→M3→M1.

In Configuration 2 (C2), the machines are arranged by placing Type 1 parts to the M1 machine and Type 2 parts to that of the M2 machine. If, on arrival, a part finds the tail of the machine to which it must be allocated, it has just processed does not have space to receive it.

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If in a run the number of pieces 1 and 2 produced is N\text{P,1} and N\text{P,2}, the gain of operation G, depends on the configuration used. Given configuration C1, we have:

\[ G(C1) = g_P,1 \times N_P,1 + g_P,2 \times N_P,2 - c_T \times k \times \{ N_{MAX,1} + N_{MAX,2} + N_{MAX,3} \} - N_{P,1} + N_{P,2} + 2N_{MAX,2} + 2N_{MAX,3} \] \times N_{P,2} \]

And for the C2 configuration, the gain is:

\[ G(C2) = g_P,1 \times N_P,1 + g_P,2 \times N_P,2 - c_T \times k \times \{ 2N_{MAX,1} + 2N_{MAX,2} + N_{MAX,2} \} \times N_{P,1} \times N_{MAX,2} + N_{MAX,3} + N_{MAX,1} \] \times N_{P,2} \]

Where gP, 1 and gP, 2 are the unit net gains for pieces 1 and 2, respectively. Transport costs are given by the maximum lengths of the product on hold s, where cT is the cost of moving a piece per unit length ($ / m$) and k is the length of a piece in the product on hold (m / piece).

The layout design consists of two stages (decisions) D1 and D2, which are addressed sequentially

D1. Select the general configuration of the plant: C1 or C2

D2. Decide the maximum sizes of the product on hold s: N_{MAX,1}, N_{MAX,2} and N_{MAX,3}

In this investigation, we seek to explore the benefit of modifying initial decisions in view of the fact that the production mix (ratio of jobs 1 and 2) deviates from its original specification. For this, we use a simulation model of the system.

V. OPTIMIZING THE SIZE OF PRODUCTION ON HOLD

Based on the simulation model, the decision of the plant configuration and the size of the tails can be represented by the following influence diagram. In these diagrams, the decisions are represented as squares and the uncertain events as ovals. (fig.12).

![Fig. 12. Configuration and production size can be represented by influence diagram.](image)

Given a configuration, the optimization of the number of product on hold s comes from an initial value of N_{MAX,1}^0, N_{MAX,2}^0 and N_{MAX,3}^0 and using simulation to carry out each evaluation. Initially, N_{MAX,1}^0+1 and N_{MAX,1}^0−1 are tested to find the direction that G increases with N_{MAX,1}. Once this address is found, continue increasing N_{MAX,1} until finding the value that provides a maximum, say N_{MAX,1}^*.

We then proceed with N_{MAX,2} y N_{MAX,3}, as shown in the following figure, where it is assumed that the improvement direction of G for N_{MAX,1} y N_{MAX,3} is increasing it with respect to, respectively, N_{MAX,1}^0 y N_{MAX,3}^0, while that of N_{MAX,2} is decreasing it with respect to N_{MAX,2}^0.

VI. RECONFIGURABLE LAYOUT

The operation of the Reconfigurable Layout, more precisely, is as follows. Let T be the planning horizon. At the time of opening, the plant operates under a C0 configuration and a spacing between N0 machines. After the time t1 has passed, the company has already identified the value of p1 and can change to the Cn configuration and Ns machine spacing with which it will operate the rest of the planning horizon. If you decide to make any changes, you will incur the lost time Δt_{IP} (fig.13).

![Fig. 13. Time of process](image)
If the profit per unit of time given the configuration $C$, the spacing $N$ and the proportion of product type 1 $p_1$, as $g(p_1, [C,N])$ the total profit of the operation under the reconfigurable layout $G_{LR}$ is calculated as:

$$G_{LR} = T \times g(p_1, [C_0, N_0]) + (T - t_1 - \Delta t_0) \times g(p_1, [C_1, N_1])$$

If the time lost by changing the spacing between machines without changing the configuration is called $\Delta t_0$ and the time lost by changing the configuration $\Delta C$, then:

$$\Delta t_0 = 0 \text{ if } C_0 = C_N \text{ and } N_0 = N_N$$

$$\Delta t_0 = \Delta t_0 \text{ if } C_0 = C_N \text{ and } N_0 \neq N_N$$

$$\Delta t_0 = \Delta C \text{ if } C_0 \neq C_N$$

A change in configuration takes longer than a change in machine spacing, so $\Delta C > \Delta t_0$

In the case of Fixed Layout, the configuration and spacing remain constant throughout the planning horizon, calling these as $C_F$ and $N_F$, the gain of the Fixed Layout $G_{LF}$ is:

$$G_{LF} = T \times g(p_1, [C_F, N_F])$$

If the variable $p_1$ can take the $p_1^i$ with the probability $P(p_1^i)$, the expected value of the gain of the reconfigurable layout will require evaluating the following decision tree. (fig. 14)

$$\Delta G_{LR} = E[G_{LR}] - E[G_{LF}]$$

VII. CONCLUSION
Among the benefits of having a flexible design is that it can be efficiently practical, with high applicability in different production requirements. The liberation or optimization of the space necessary for the improvement of the flow of the stations and the personnel, therefore, this will resume in the increase of the productivity. Simpler production process to follow and control. Reduction or extraction of distances and times dedicated to transport and storage, therefore, reduction or elimination of tasks that are not in accordance with the value and unnecessary costs. With the reconfigurable design and leaner machinery, we can make operations more flexible, adjusting better to fluctuations in demand.

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Ricardo I. Ramírez Guzmán born in the State of Mexico, Mexico, on September 1, 1999. Graduated from the Mechatronics Engineering bachelor degree, at Universidad del Valle de México, in Mexico City, Mexico in 2014. He is currently studying the Master of Science in Industrial Engineering at Tecnológico de Estudios Superiores de Coacalco, Mexico. He worked at Cuprum de México S.A. de C.V., Tlahualipantla de Baz, México, as Maintenance Supervisor of the foundry and vertical painting , 2013-2014., At Ashcroft de México S.A. de C.V., Naucalpan, México, As production / maintenance manager, 2014-2016. , Instituto Mexicano del Seguro Social, Mexico, As chief of conservation of medical area, 2016-2018. , Sachaesung Alabama Inc, Georgia Alabama. United States, Assembly Line Maintenance Supervisor. 2018-2019. , Universidad del Valle de México, Coacalco, México, Master of the course in Mechatronic Engineering, 2019-Present. PhD.Chew, Doctor of Philosophy, University of Nottingham, England. Full-time Professor / Researcher Tecnológico de Estudios Superiores de Coacalco, Master in quality, science and technology, Universidad de Tlaxcala, Mexico. Full-time Professor / Researcher at Tecnológico de Estudios Superiores de Coacalco.