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A VISUAL TOOL TO OPTIMIZE THE SHOP

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ABSTRACT
This paper presents the O-T Diagram (Operations versus Time), an updated computerized-version of the classical Gantt chart in order to simulate the behavior of complex production systems. O-T diagrams are useful to understand the behavior of production systems, in terms of their real lead-time (time elapsed from the moment a production order starts being manufactured till the moment when the last unit has been finished) and work in process inventory. Once the relation between key magnitudes is clear, the optimization process can start.
Keywords: lean manufacturing, Work in process, Gantt chart

1. SIMPLE THINGS LAST MORE THAN A LIFETIME
Henry Gantt, one of Taylor's collaborators, presented his famous bar in the early days of the Twentieth century. Ever since, this tool has been used to plan, schedule and control production processes, according to the availability of machines and men, and to schedule complex projects (a field where Gantt charts managed to survive when PERT/CPM charts were introduced in the 1960s.) The tool is also used in service companies like hospitals or even to plan the plot of TV series. How can we explain this long life while there are so many passing fads in the environment of management? It can be attributed to the apparent easiness of the method because no calculations are needed, and to the fact that the results are easy to understand because they are presented in a graphic mode: the beginning and the end of every activity are displayed and specific values of time (milestones) can be found on the horizontal axis. In this paper, Gantt charts are updated and represented on an electronic spreadsheet including macros and some programming.

2. O-T DIAGRAMS IN THE LEAN ERA
Nowadays, in the first decade of the Twenty-first Century, companies need to be competitive and reduce its costs while increasing flexibility (the ability to change from one product to another and adapt to the needs of the client in terms of quantity and delivery). To reach that goal, companies need to know what's wrong with their processes, how good or bad they are and where they must be optimized. Lean manufacturing has been used, apart from the automotive industry, in companies like a steelworks [1] proving that the lean way it is good system to increase the efficiency of such industries. Lean Manufacturing is based on the concept of *muda* or waste: all the operations and activities that do not add value to the product from the point of view of the consumer must be avoided [2]. Amongst such activities, we focus on waiting time (that leads to a long lead time) and inventories (also related to waiting time because a group of pieces are waiting to be processed). The Theory of

Constraints focuses on the “bottleneck”: the slowest operation, which sets the pace for the others operations, where either inventories will grow or operators and machines will have to wait [3].

Lean management insists in visual planning, like value stream map [4], and other visual tools like 5 S [5] (which literally marks the space for machines, inventories, tools.). In this context, our O-T Diagram, also a visual tool, allows the visual deterministic (usually lean manufactures relies on deterministic phenomena because leaving things to chance is considered a source of waste -It would be a “just in case” process rather than a “just in time” one) simulation of the behavior of a complex production system, with multiple processes, with transfer batches that may be different from each other and it makes easy the calculation of the total lead time and the amount of work in process, magnitudes closely related to flexibility and efficiency, thus giving an insight into the overall process and providing an understanding of the effect of the possible improvements.

3. FIRST THINGS FIRST

Firstly, a simple process will be represented. Lets consider a process that consists of N operations with the same cycle time *C* each (perfectly balanced process). This process yields a production batch of Q units of finished product, divided in *n* transfer lots (with *Q/n* units in each). By means of the manual O-T diagram (Figure 1) we realize that, once all operations are processing parts (remarket with a vertical white arrow), the total inventory of parts in the process is the number of parts in every operation (*Q/n*) times the number of operations (Equation 1). Lead time (LT) for the first primer transfer lot is the time that passes between the start and end of the manufacturing of this first lot. According to Figure 1, it can be described as the cycle time (for any operation) times the number parts (time needed to process the whole transfer batch in every operation) times the number of operations (Equation 2). A combination between Equations 1 and 2 gives the relation between work in process inventory (WIP) and lead time (Equation 3): there is a direct relation between WIP and LT and if one of them increases the other does the same, while if one of these magnitudes is cut in half, the other will also be reduced.

$$WIP = \frac{Q}{n} \cdot N \tag{1}$$

$$LT = \left[C \cdot \frac{Q}{n} \right] \cdot N \tag{2}$$

$$WIP = \frac{LT}{C} \tag{3}$$

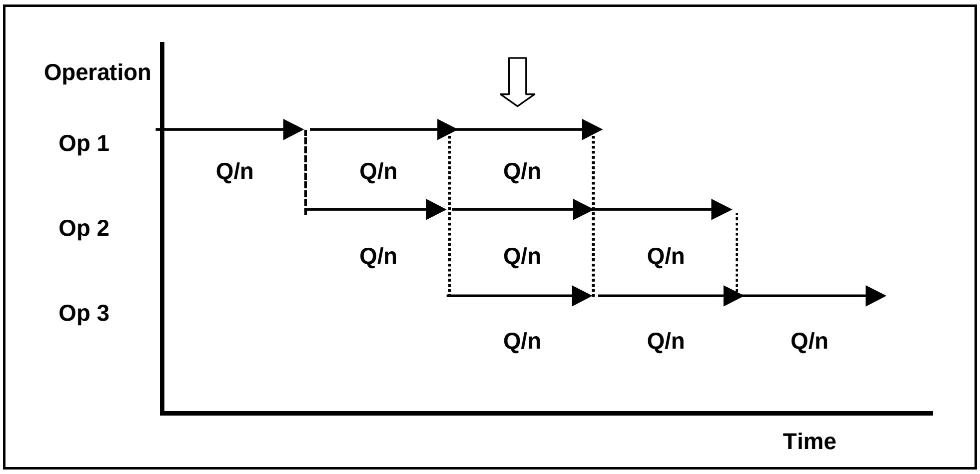

Figure 1. Simple O-T diagram for a balanced, synchronous process.

4. SIMULATING HARD PROCESSES

Now, a more complex situation (Figure 2) can be discussed. Let's consider an unbalanced process [6] where operations have different values for their cycles (*Ci*). As a consequence, lead times will be different for every transfer lot (*LTi*). That leads to an increase in WIP inventories because parts trying to get into an operation may have to wait (*tc2*) till the operation is idle. Thew model can also include setup times (*TPi*) and different values of the transfer lot size for different operations.

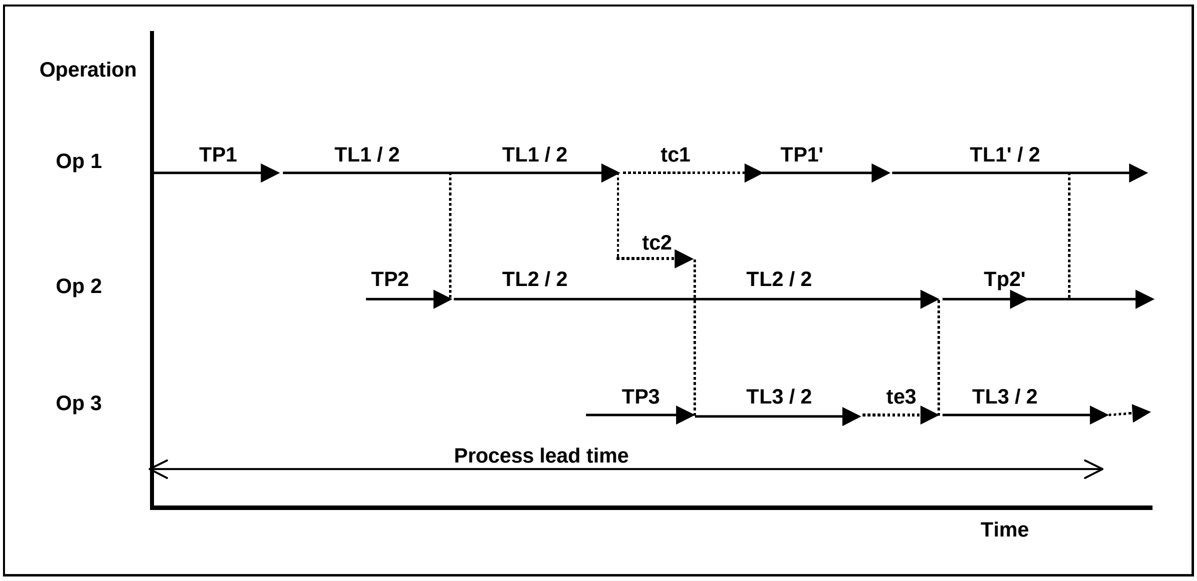

Figure 2. O-T Diagram for an unbalanced process with different cycle times and different lot sizes.

If we consider the first transfer lot, Equation 3 is still valid but now cycle time is the cycle for the first operations (C_1), which sets the pace at which parts enter the process. Equation 1 can be used on condition that, at the moment considered (*T*), the first unit has reached the last operation and more parts are still entering the first operation. When the first transfer lot has been processed, new parts entering the process will make the WIP figures grow unless the rhythm at which these units enter the process (first operation) is the same at which other units leave it (last operation) - that coincidence would happen if the first operation was the slowest (longest cycle time C_M) or all operations had the same cycle time (balanced process)-

If WIP inventories grow, lead time will also increase (according to Equation 3). That is to say that theirs values are unstable. To avoid an increasing WIP inventory, pieces must enter the process according to the needs of the bottleneck operation (for example, using a kanban).

According to everything explained, we can develop an equation to describe the relation between time and WIP (Equation 4)

$$WIP = WIP_1 + \Delta WIP = \frac{LT_1}{C_1} + (T - LT_1).(\frac{1}{C_1} - \frac{1}{C_M}) = $$
$$= T.(\frac{1}{C_1} - \frac{1}{C_M}) + \frac{LT_1}{C_M} T.(\frac{1}{C_1} - \frac{1}{C_M}) + \frac{Q}{n.C_M}.\sum^{N} Ci \qquad (4)$$

If we consider the moment $C_1 \cdot Q$, when the whole production batch has entered the process, we get the maximum amount of WIP inventory . That leads to the calculation of the lead-time for the whole production lot, and the lead time of the last transfer lot. The length of the lead-time of the firs transfer lot compared with the length of the lead-time for the last transfer lot gives the gives total amount of time lost (D) waiting or delay in the process (Equation 5). Equations 1 to 5 show the relations between the key magnitudes of the process and give clues to optimize it. When processes are more complex, analytic expressions cannot be obtained but at least the O-T diagram allows its simulation [7] in order to estimate the effects of some parameters on the process.

$$D = \left[LT_1 + C_M . \frac{Q}{n}(n-1) \right] - \left[LT_1 + C_1 . \frac{Q}{n}(n-1) \right] = (C_M - C_1). \frac{Q}{n}(n-1) \qquad (5)$$

5. CONCLUSIONS

In this paper, we have seen what elements are responsible for creating work in process inventories. Let's now summarize them and comment on their relation with lean management: a) the number of units to be manufactured (*Q*). Lean manufacturing considers overproduction one of the types of waste; b) the length of the longest cycle time and the sum of all the cycle times. For this reason, Lean manufacturing tries to improve all operations with techniques like 5S, kaizen and SMED; c) The transfer lot size. Lean manufacturing defends one-piece flow processes, many times implemented on cellular layouts.

In a similar way, we have found expressions for the lead-time and the delays: a) When *Q* and *Q/n* increase, so do the lean time and the process delay. In order to reduce them, *Q* must be as small as possible (without overproduction) and the transfer lot size ought to be one; b) The more unbalanced the process (differences between C_1 and C_M) , the more delays it experiences.

As a final conclusion, the paper shows how O-T diagrams can be used to simulate processes. When processes include many more operations than those illustrated here deterring us from analytic calculation, total lead-time, cycle time and delay can be directly observed on the horizontal axis. Then, work in process inventory can be estimated by means of Equation 4.

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