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Measuring the impact of Lean tools on the cost–time investment of a product using cost–time profiles

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Abstract

Traditional costing systems consider the accumulation of costs, but not their timing. Value stream mapping presents a good picture of the time consumed and operations performed for the production of a product within a manufacturing facility, but it does not track the accumulation of costs. The cost–time profile (CTP) is a tool that follows the accumulation of cost in the manufacturing of a product through time; and it finds the cost–time investment (CTI), which is an indicator of the use of resources in the manufacturing of a product through quantities and timing. In this paper, the expected impact of Lean implementations on the CTP and CTI is discussed. The CTP is proposed as a useful tool for the evaluation of the improvements achieved by the implementation of Lean tools and techniques.

Keywords: Lean manufacturing; Cost–time profile; Cost; Investment

1. Introduction

The determination of the cost of a product by evaluating the use of resources in its manufacturing, has always been a matter of great importance for companies. Traditionally, two approaches have been used. The first one is the "accounting" approach, in which the costs of a product are accumulated through different costing systems. This approach has been used especially for financial reporting purposes, but it has been criticized by different authors [1,2] for its lack of usefulness in decision making. The second approach, which has seen widespread adoption in the last 15 years, is the construction and use of value stream mapping (VSM) to visualize the production process and its associated usage of resources.

Both approaches have been useful in the evaluation of a production process and in the control of its performance. However, they are almost mutually exclusive in their focus. Traditional cost accumulation is only concerned with the monetary aspect of manufacturing, whereas VSM highlights operating procedures and use of different resources, mainly time, but it ignores costs and monetary data.

In response to this lack of a simple tool that accounts for money (costs) and time simultaneously, we propose the use of cost–time profiles (CTPs). A CTP is the graphical presentation of the accumulated cost in the manufacturing of a product, followed through every time unit. The CTP focuses on direct costs, since the discussion about the right way to allocate overhead to products is far from settled. The main concepts of CTP were developed in the late Westinghouse Corporation [3], as a way to simultaneously monitor their manufacturing processes in the use of money and time. It will be explained how this CTP can be built and used.

In this paper, we briefly present the procedure followed for the construction of the CTP, focusing on its uses and applications. It especially emphasized the study of the expected impact that the implementation of Lean tools and techniques might have on the CTP. Also, how this tool can be used to economically evaluate and justify the necessary investments that occur in Lean implementations.

2. What is a CTP?

A CTP is a graph that depicts the accumulated costs that have been expended during the manufacturing of a product

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at every time unit during the process. This way of presenting the information follows the use of resources through time, from the moment the production process begins until the company recovers those invested resources through the sale of the product. The area under the CTP is called the *cost–time investment* (CTI), because it presents how much money has been tied up in the manufacturing process and *for how long* before being recovered through sales. The reader will recognize the term investment because the CTI shares the two common components of any financial investment: money and time. Fig. 1 gives a simple illustration of a CTP.

The graph of the CTP has several distinct elements that must be mentioned and described.

- *Activities*: There are two assumptions regarding activities. The first one is that their costs (except for materials) are incurred continuously, from the beginning of the activity until its end. The second assumption has to do with the use of materials. Materials have to be ready for their use before the activity can begin; therefore, it is assumed that they must be released prior to the beginning of the activity (more details in the next bullet point). Activities are represented in the CTP as line segments with positive slope.
- *Materials*: Materials are presented in the CTP as vertical line segments. The reason for this is that materials are received "instantaneously" and their costs are added to the product cost in this manner. Materials have to be ready before the beginning of an activity, but they can be released to the process (and added to the cost) just in time (the materials used by each activity are released right before the beginning of the activity) or at the beginning of the process (all the materials required for the product are released together before starting the first activity). Once materials are released into the process and added to the product cost, they continue as part of the accumulated cost because they will not be recovered until the product is sold.
- *Waits*: These are moments in the process at which there are no activities happening. The underlying assumption is that when a product is waiting, no cost is accumulated onto it. Although this assumption might be easily challenged, it must be remembered that the CTP only focuses on "direct" costs, and not on overhead. Costs that are incurred while waiting will probably fall under the category of overhead. Waits are presented in the graph as horizontal lines (zero slope). However, they are very important because it is commonly known that there is a considerable amount of non-value-adding time in manufacturing processes. Waits underscore the importance of the time element, because even though they do not actively add cost, they prolong the time the investment is made on the product before recovering costs through sales.
- *Total cost*: Total cost is the addition of all the direct costs that are incurred in the manufacturing of the product, without yet considering the impact of CTI and the time value of money. Total cost is the height of the graph at the moment the cycle finishes and the costs are recovered through sales.
- *CTI*: The area under the CTP profile represents how much and for how long costs have been accumulated during the manufacturing process. It is the composition of the cost and time dimensions. The CTI has implications on the direct cost of the product and the budgeting of working capital for the company that will be discussed in subsequent sections.
- *Direct cost*: Since the CTI is an actual investment, its cost can be determined multiplying it by the appropriate interest rate (IRR, cost of capital, cost of lost opportunities). The direct cost would then be the total cost plus the investment cost:

$$\textit{direct cost} = \textit{total cost} + (\textit{cost}-\textit{time investment} * \textit{cost-of-money-rate}). \quad (1)$$

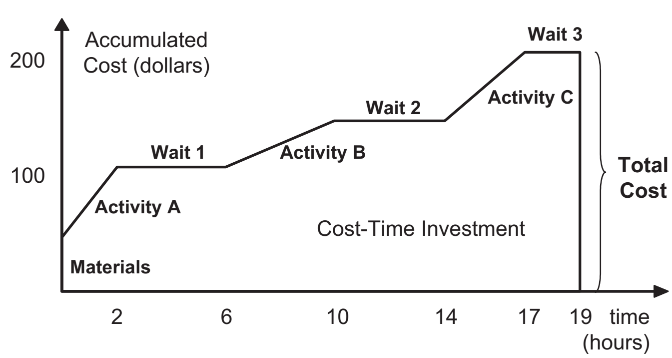

Fig. 1. Example of a cost–time profile.

3. How to build a CTP?

To build a CTP, we need to know several things. First, we need to know *when* is each element of the CTP happening (activities, waits and materials releases). We also need to know *how much* does each of these elements cost. Putting the two previous points together we can determine *how much* money is being spent as cost *at every time unit* in the process. Finally, we tally the costs and build the CTP with the *accumulated cost* at every time unit, and present this information in graphical form. The area under the curve (obtained adding the accumulated cost at each time unit for all the time units) represents the CTI. In the following subsections, a brief discussion on how to complete these steps for the construction of the CTP will be presented.

3.1. When do the CTP elements happen?

The company should have a map of their production process, specifying when activities, material releases and waits are happening. If this is not available, it will be necessary to document the process, much in the way it would be done to construct a VSM.

At this point, the process that the company has does not necessarily guarantee that the best possible CTI will be attained. To ensure that this is the case, it is possible to employ the project management type of network graphs and their associated solution methods. These solution methods usually focus on finishing the project in the shortest possible time, but the objective function can be modified to achieve the best configuration for a smaller CTI [4]. We will not go into the details of these methods in this paper, as they will be made available elsewhere. Finishing this phase, we should have a defined schedule that shows when the elements of the CTP are happening.

3.2. How much does each element of the CTP cost?

Material releases: The cost of a materials release will be its full cost for the company.

Activities: The cost of activities includes the costs of the operators and resources that are utilized to perform the activity. The per time unit cost rate of operators and resources must be known to the company and be determined by the preferred company method. Again, overhead is excluded from these calculations.

Waits: Waits do not add cost to the accumulated cost. However, they have an impact on the CTI because they enlarge the area under the CTP curve, delaying the recovery of costs through sales and therefore making the CTI bigger. This in turn increases the direct cost of the product.

3.3. How much accumulated cost is there at each time unit?

In Section 3.1 we determined *when* CTP elements happened, and in Section 3.2 we found out *how much* do these elements cost. Combining these two sets of data we can now calculate how much cost are we adding *at each time unit*. For this purpose, we treat time units as discrete entities. We then present the accumulated cost at each time unit in graphical form, thus building the *CTP*. The *CTI* is determined by adding the accumulated cost in each time unit over all the duration of the manufacturing cycle of the product. The *total cost* is the value of the accumulated cost at the last time unit of the process. Finally, the *direct cost* can be calculated using Eq. (1). For an example of the finished CTP please refer to Fig. 1.

4. Scenarios for the reduction of the CTI

From all the information presented above, it should be obvious that the reduction of the CTI (and the direct cost) in the manufacturing process of a product is a desirable improvement path. In this section, we will present some common generic scenarios for the reduction of the area under the CTP curve. In the next section these generic scenarios will be used to present the foreseen impact of Lean tools and techniques on the CTI and direct cost.

4.1. Reduce the cost of materials

If we are capable of manufacturing the same product (maintaining its performance and quality constant) by using either a smaller amount of the same materials, replacing materials with cheaper alternatives or buying the same materials from a cheaper source, then the area under the curve would be reduced and both the CTI and the direct cost would be decreased, as shown in Fig. 2.

4.2. Release materials just in time

The example of CTP presented in Fig. 1 assumes that the delivery of all the materials necessary for the manufacturing process occurs at the same time before the beginning of the first activity. Instead, we might consider the partial release of materials to the process right before each activity that requires them. This would reduce the CTI because of the timing of the material expenses as it can be observed in Fig. 3.

4.3. Reduce waiting

The original CTP presented in Fig. 1 has three waits: Wait 1, Wait 2, and Wait 3. If we assume that all the waits

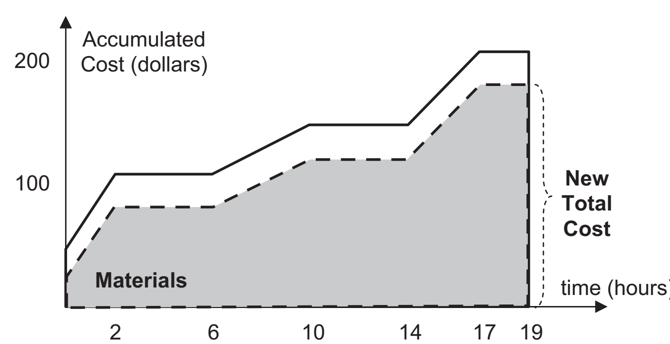

Fig. 2. Reduce the cost of materials.

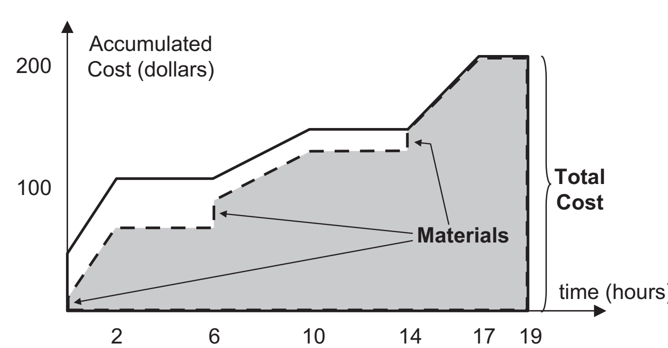

Fig. 3. Release materials just in time.

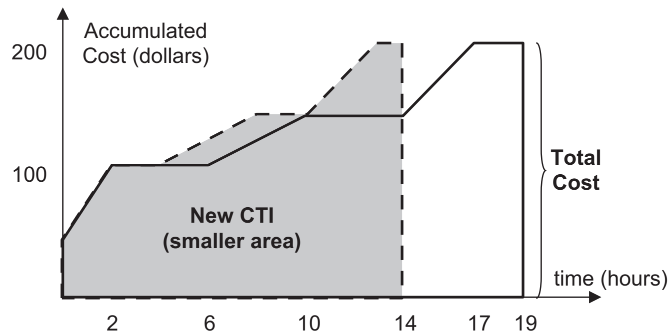

Fig. 4. Reduce waiting.

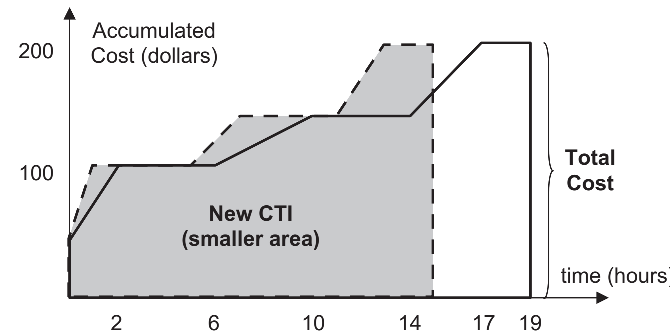

Fig. 6. Reduce the duration of activities.

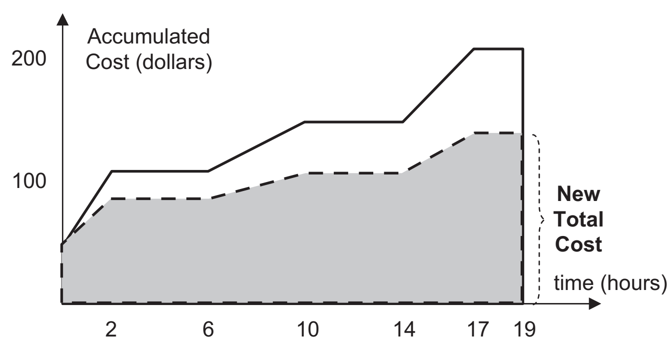

Fig. 5. Reduce the cost of activities.

will be cut in half (not an uncommon improvement in the Lean literature), the result will be a smaller area under the CTP and therefore a smaller value of the CTI. This scenario is presented in Fig. 4.

4.4. *Reduce the cost of activities*

If the cost of activities is reduced, the slope of the diagonal lines will decrease, finishing in the same total time but with a smaller total cost and therefore smaller CTI. This scenario is presented in Fig. 5.

4.5. *Reduce the duration of activities*

If activities are performed faster, the area under the CTP curve (CTI) will be reduced. Even if activities have the same total cost (and therefore, the total cost stays constant), their earlier completion will reduce the CTI. This scenario is presented in Fig. 6.

After presenting the generic scenarios for the reduction of the area under the CTP curve (CTI) and the direct cost, we will discuss how a typical implementation of Lean tools and techniques might have an impact on the CTI and direct cost of a product. To this end, we will discuss an improvement framework and then we will match the effect of the different Lean tools and techniques to the generic scenarios presented in this section.

5. Impact of Lean implementations on the CTP and the CTI

Most of the Lean tools and techniques are good industrial engineering practices that can be applied to companies in many contexts and without a lot of difficulty. However, the real impact that can be obtained from these tools and techniques is realized when they are implemented as part of a Lean improvement effort. In this way, improvements have a better chance of being sustained.

In this paper, a particular improvement framework will be employed, with the observation that there are many feasible and valid approaches to Lean implementations. This is one that is logical and easy to understand [5]. Its basic structure is illustrated in Fig. 7.

From this structure, a subset of techniques was extracted, trying to highlight those tools that have a more visible impact on the investment. These tools are those that reduce the waiting time, the processing time, the cost rates and deliver the materials JIT at the moment and place where they are needed. This subset is presented in Fig. 8.

These techniques are grouped in "Waves", according to the type of savings they help realize. In the following subsections a brief discussion of each Wave will be presented.

5.1. *First Wave of a Lean implementation*

The first Wave will be aimed at reducing the waiting time by dedicating groups of equipment to the production of specific families and coupling them more closely together. Ideas such as group technology, cellular manufacturing and focused factories will be applied to achieve this coupling.

Also, the application of 5S will decrease the waiting related to finding the tools for processing, straightening the equipment and supplies and in general being ready for work in a quicker manner, thus reducing the waiting time. In this first wave, the typical improvements expected correspond to those outlined in Section 4.3.

5.2. *Second Wave*

The second Wave will be implemented after first Wave, using it as a base point to improve further. In this case the

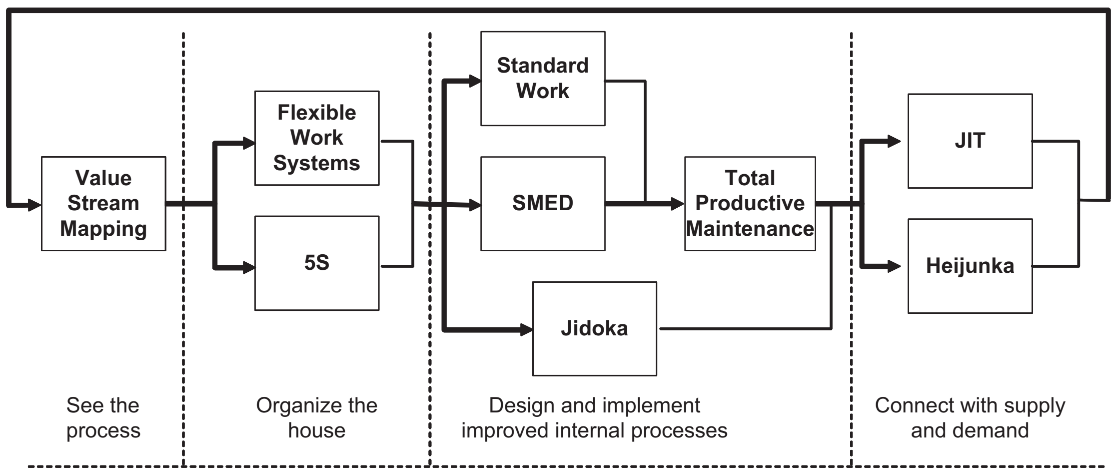

Fig. 7. Typical process for a Lean implementation (modified from [5]).

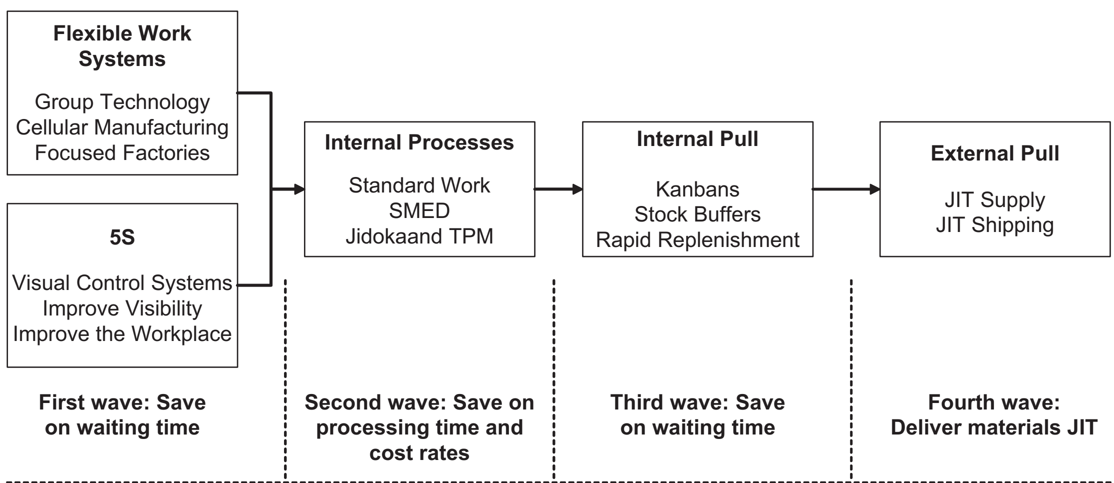

Fig. 8. "Waves" of Lean implementation.

improvement and standardization of internal processes is the main focus. Tools such as Standard Work (finding, documenting, disseminating and implementing best practices in the job), SMED (dramatically reducing the time consumed by changeovers and setups), Jidoka (a set of practices including autonomation and mistake-proofing designed to improve the quality of the process and the resulting products) and TPM (which increases the availability of machines therefore reducing the cost of maintenance) will be used to improve the processing times and practices, therefore reducing processing times and cost rates.

The expected improvements correspond to the scenarios of Sections 4.4 and 4.5, with final improvements probably found in both cost and duration of activities.

5.3. Third Wave

In the third Wave, another reduction on the waiting time is realized. The implementation of Pull Systems in the company should promote a further reduction on the waiting time. Now, there will be much less inventory lying around in the company between operations, and those WIP piles removed are exactly equivalent to the elimination of waiting time. Therefore, the impacts again are analogous to those presented in Section 4.3.

5.4. Fourth Wave

Once all the previous steps have been applied, the introduction of JIT practices will distribute the delivery of materials to the process more efficiently. Now, instead of receiving (and charging) all the materials together before the beginning of the production process, only the necessary materials are received immediately before the beginning of each activity. The foreseen impacts will be analogous to those presented in Section 4.2.

5.5. Individual tools and techniques

Lastly, Table 1 presents a proposed impact of individual Lean tools and techniques [6,7]. This does not mean that individual implementation of techniques is proposed.

Table 1
Expected CTP and CTI impact of Lean tools and techniques

Tool or technique	Expected improvement
Group technology	Waiting time
Cellular manufacturing	Waiting time
Focused factories	Waiting time
5S	Waiting time, activity duration
Visual control systems	Waiting time, activity duration, activity cost
Standard work	Activity duration, activity cost
SMED	Activity duration, activity cost
Jidoka	Activity duration, activity cost, reduce materials
TPM	Activity cost, reduce materials
Kanbans	Waiting time
Rapid replenishment	Waiting time
JIT supply	Waiting time, JIT materials
JIT shipping	Waiting time, JIT materials

Rather, it is an attempt to characterize the types of improvements expected from typical tools and techniques if they were evaluated employing tools such as CTP and CTI.

6. Conclusions

The use of the CTP will improve the accuracy of the direct cost for products, because it reveals a hidden cost that has not been accounted for (the investment cost, Section 2). The recognition of this hidden cost will also lead to its inclusion in the budgeting of the working capital. It also underscores the importance of the time dimension in manufacturing as a prime factor in the determination of costs.

When VSM [8,9] became popular, it was visible that a significant amount of the time products spent on the production system usually was waiting and non-value-adding time. This also explains the fact that many of the Lean tools have an expected impact related to the reduction of this waiting time. The evaluation of these improvements through the use of the CTP and the CTI highlights the economic impact of time improvements.

The CTP can be used to assess the expected impact of a change in the production process. There might be savings and new costs that are not completely evident and can be revealed through the construction of a CTP. For instance, the switch to operations that are quicker but more costly or slower but more economical might have an unforeseen impact in the CTP and CTI that could make discarded options attractive again.

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