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WASTE IDENTIFICATION DIAGRAMS

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ABSTRACT: *The most popular and perhaps the most effective way to represent the material flow in production units is the diagram known as Value Stream Map (VSM). Moreover these maps are also used to help in the identification of waste as well as a tool to support continuous improvement. Nevertheless, many of VSM limitations are known and thus there is room for the creation of other more effective ways to represent productive units as well as helping the identification of production waste. This paper presents a new graphic representation model for production units, as a tool to identify three forms of waste, designated as Waste Identification Diagram (WID), which aims to provide information to top managers in a much more effective format. The WID is a network of blocks and arrows, showing visually the throughput times, idle capacity, transport effort, changeover times and work-in-process levels. To illustrate the main features of this new tool, the paper includes a WID of a real production unity.*

1. INTRODUCTION

In 1988 Taiichi Ohno presented in his book "Toyota Production System: Beyond Large-Scale Production" [Ohno, 1988] the seven wastes (muda) responsible for manufacturing systems' low productivity. The types of waste were identified as: over-production, over-processing, inventory, movements of people, transportation of materials, non-conformity of products and people waiting. According to Taiichi Ohno, the existing wastes, along with inadequate flow of production, are sources of losses and, therefore, need to be identified and eliminated. The knowledge about the *Gemba* (shop-floor) is crucial to waste identification. Locations with high inventory (probably the most "visible" waste) are not difficult to spot but, most likely, that inventory is a consequence of other hidden wastes. Thus, the importance of representation tools specifically designed to identify waste within a manufacturing system, seems to be obvious.

The main purpose of this paper is the introduction of a new visual tool able to highlight three types of waste associated with the items flowing on the shop floor, namely inventory, overproduction and transport. This tool is designated as Waste Identification Diagram (WID), and is developed by the Production and Systems Department at University of Minho, Portugal.

The paper is organized as follows. After this introduction, section 2 provides a brief review of some representation tools, for production systems, considered by the authors as relevant in the context of this work. Section 3 describes the fundamentals of the developed tool (WID) and introduces the main elements of the correspondent graphical notation. An application example, based on a real industrial scenario, is presented in section 4. Finally, on section 5, some concluding remarks are outlined.

2. TOOLS FOR MANUFACTURING SYSTEMS REPRESENTATION

Currently there are a number of methodologies to build graphic representations of production systems, in order to help managers to describe, analyse and diagnose these systems. Value Stream Mapping (VSM), introduced in ref. [Rother and Shook [1999], is probably the most popular example. The VSM has revolutionized the graphic representations of production systems, and its main objective is the representation of production and information flows, where some of the existing waste (muda) may become easily identifiable (e.g. inventory and over-production), especially by lean experts. Ref. [Serrano et. al 2008] state that VSM is undoubtedly an innovative tool presented in the context of lean production. However, other authors pointed out a number of limitations. For example, ref. [Gahagan, 2010] acknowledges that VSM is a powerful tool to help the implementation of lean manufacturing, but refers, as limitation, the difficulty in transmitting the results to other players when they are not familiar with that methodology. According to ref. [Nazareno et al, 2003; Chitturi et al., 2007], the VSM has major limitations in the representation of production systems characterized by high diversity of products and several production routes. Finally, VSM is focused on materials and information flows and does not represent the flow of people.

The flow process chart constitutes another type of graphical representation commonly used in the area of industrial engineering [Courtois et al, 1997]. Flow process charts are intended to represent the sequence of operations involved in the production of a given product, or family of products. Specific symbols were created to represent processing operations, transportation of materials, storage, buffers and inspection. Although not designed for that purpose, flow process charts can identify some wastes, namely inventory and transportation of materials. However, these charts do not include any kind of quantification, being thus of limited use in the context of waste identification. Additionally, flow process charts are focused on the flow of materials and the workers' role is not addressed.

Somehow contrarily, the approach named "treasure maps", described in ref. [Kobayashi, 1995] is focused on the workers' role and does not address the materials flow perspective. This approach creates a map with the location of wastes associated to workers' activities (mainly, movements and waiting) and it is based on work sampling studies conducted by teams throughout the entire production system. "Gold mines", "silver mines" and "cooper mines" are designations used in the "treasure map" to identify the areas where waste occurs, by decreasing order of degree of wastefulness [Kobayashi, 1995]. The main reason behind the development of this approach was the fact that many workers, and managers, do not have a clear understanding of what is waste.

Simulation is commonly applied in the design of production systems and to evaluate proposed improvements to existing systems. This tool, due to its dynamic nature, allows the identification of some wastes, namely, inventory, movements of people and transports of materials. However simulation demands the utilization of specific software tools (most of them proprietary) and a considerable level of expertise.

To overcome some of the limitations of the previously described approaches/tools, but mainly to explore a different visual mechanism (innovative within the representation tools commonly used in the production systems area), a new tool called Waste Identification Diagram (WID) was developed in the Production and Systems Department at University of Minho, Portugal.

3. WASTE IDENTIFICATION DIAGRAMS (WID)

In this section it is presented a new powerful representation tool - WID - to help managers to identify most forms of waste on their shop floors. WID allows the description of production units, visually highlighting the main problems that prevent companies to achieve streamlined production flows. The WID is easy to understand (due to the semantics of the developed graphic notation), allows an immediate visual diagnose of the most relevant locations of waste and can be used as a continuous improvement tool. With WID it is possible to represent not only a single production route (of a given family of products), but many - the only limitation is the size of the diagram.

3.1. Fundamentals

Two important fundamentals involved in the WID development process are the well-known visual control and Little's Law [Little, 1961]. The basic concepts of line balancing, transportation effort and setup time were also considered.

Visual control is one of the tools associated to the lean production paradigm and intends to provide an immediate visual perception about some relevant aspect (e.g. state of a production process, work instructions, safety stock). Somehow, WID borrows this concept of immediate visual perception and apply it to waste identification. In fact, as described in the next section, the physical dimensions of the icons used to construct WID are proportional to some wastes (e.g. inventory and transportation of materials). This constitutes the main distinctive characteristic of WID when compared to other representation tools (section 2).

According to Little's Law the throughput time of a given process can be obtained multiplying the WIP (Work-In-Process) in that process by the Cycle Time (instead of Cycle Time the authors use the Takt Time since it is more realistic in real production environments). WID represent this multiplication (i.e. the throughput time) as the frontal area of a specific tridimensional icon (Fig. 1) providing thus an immediate identification of the problematic areas (the larger the area, the larger the throughput time).

The Waste Identification Diagram is basically a network of two types of icons: the block icon representing workstations and the arrow icon representing transportation of parts.

3.2. Block icon

This is the main icon type on Waste Identification Diagrams (WID). Each block in the WID represents one process or a group of processes (a workstation, a production cell or any other production unit), connected to other blocks by transportation arrows. The size of each block depends on four variables, namely, Takt Time (TT), Cycle Time (CT), Work In Process (WIP) and Changeover time (C/O) (Fig. 1).

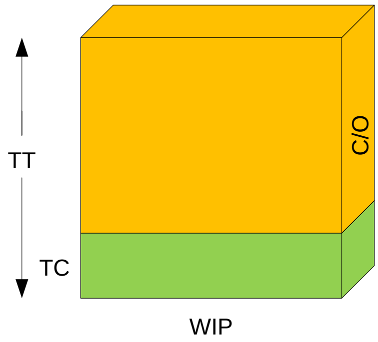

Fig 1. Block icon

The width of the block (X axis) is related to the WIP on that process. The units used to measure WIP may be number of parts, weight units, length units, volume units or their value (currency). The height of the block (Y axis) corresponds to the Takt Time and the height of the green part is the Cycle Time of that process. The difference between the Takt Time and the Cycle Time (CT), shown in orange, represents the unused capacity for that process. The units used for TT and CT are time units (e.g. seconds, minutes or hours) per part.

The depth of the block (Z axis) represents the changeover time or setup time for that process or workstation. When a process needs large setup times a natural and classical consequence is large levels of WIP associated with it. In this way, may be expectable that thicker blocks (blocks with high values of C/O) would also be wider (blocks with high values of WIP).

One of the first interesting results of such representation is that, according to Little´s Law [Little, 1961], the frontal area of the block (green area plus orange area) represents the throughput time of the process. Thus, when observing the blocks, large areas represent large throughput times.

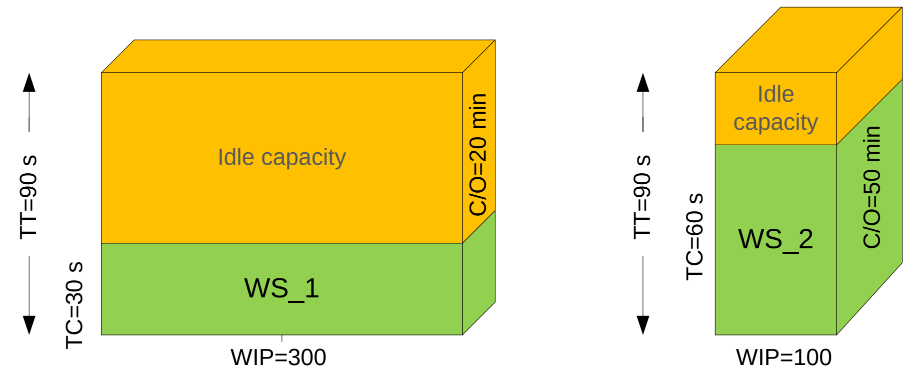

Fig 2. Two block icons representing two different processes

In order to clarify the meaning of the visual information available on block icons, observe Fig. 2. Assume that those blocks represent two different processes required in the process route of a product or family of products (please note that the Takt Time is the same in both processes since the Takt Time is product related). The first obvious information that can be extracted simply by looking at the blocks is that the bigger is the block the higher is the waste associated with it. Assuming that big blocks means big waste, Fig. 2 immediately reveals that the WS_1 is creating a lot more waste than WS_2. Other obvious information coming from a simple look at the blocks is that idle capacity exists more on WS_1 than on WS_2.

Other visual information can be easily obtained, such as:

- Work Station 1 (WS_1) holds more WIP than Work Station 2 (WS_2).
- WS_1 has more idle capacity than WS_2.
- WS_1 and WS_2 are not balanced.
- The lead time of WS_1 is higher than the lead time of WS_2. This is observed by the frontal area of each block.
- The Changeover time for WS_2 is higher than the changeover time for WS_1.
- Based on the information available, the amount of WIP associated to WS_1 does not make sense since both the changeover time and cycle time are low.

Broadly it may be stated that there is more waste associated to WS_1 even without a known reason. It does not make sense so much WIP associated to WS_1 as its changeover time is lower than the changeover time of WS_2 and also because WS_1 has plenty of spare capacity. Just with this information, the manager would need to find out why the inventory associated with WS_1 is so high. Sometimes there are important reasons but in other cases it happens because no one is paying attention to it.

Another important piece of information coming out from these blocks is the throughput time (lead time) of each process, i.e., the area of the front face of each block. As previously mentioned the lead time, according to Little's Law, is obtained multiplying the Takt Time by the existing WIP. As can be seen from Fig. 2, the lead time associated to the WS_1 is 3 times larger than the lead time of WS_2. Since the throughput time (and WIP) of WS_1 is so high, special attention must be paid to that workstation in order to find out the reasons behind so much inventory.

3.3 Transportation Arrow

Besides the block icon representing the two worse classic types of waste, which are inventory and over-processing, being associated to a process, the WID also allows the representation of another classic type of waste - the transportation waste, associated to the transportation of parts between processes. The transportation arrow (Fig. 3) intends to represent the effort needed to move the parts from process to process. The length of the arrow was decided to stay constant for practical reasons since different arrow lengths could make the diagram difficult to understand because of the scale problem. The thickness of the transportation arrow varies according to the transportation effort associated to the connection from the supplier process to the client process. The effort may be measured in parts*meter, kg*m, cost units (€) or any other way of measuring transportation effort.

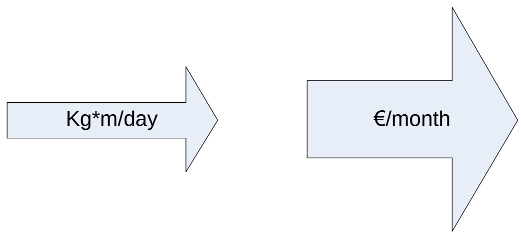

Fig 3. Transportation arrows with different thickness and measuring units

Since the thickness of each transportation arrow on the diagram is proportional to the transportation effort, the thicker arrow on the diagram is associated to the transportation segment with more room for improvement. In continuous improvement logic, actions should be drawn for thicker arrows in order to make them thinner (leaner) probably changing layouts approaching the corresponding client and supplier processes.

4. WID APPLICATION

This section presents the application of the WID concept on a real production unit, more specifically in a production section of a company dedicated to the manufacture of picture frames. The information about cycle times, takt times, changeover times, and production routes was given by the production department personnel while the information about work in process (WIP) and travelling distances had to be collected by the authors on the shop floor. The WID generated is presented in Fig. 4. The values of WIP in the diagram are the values observed on a specific date and assumed as typical values representing normal condition.

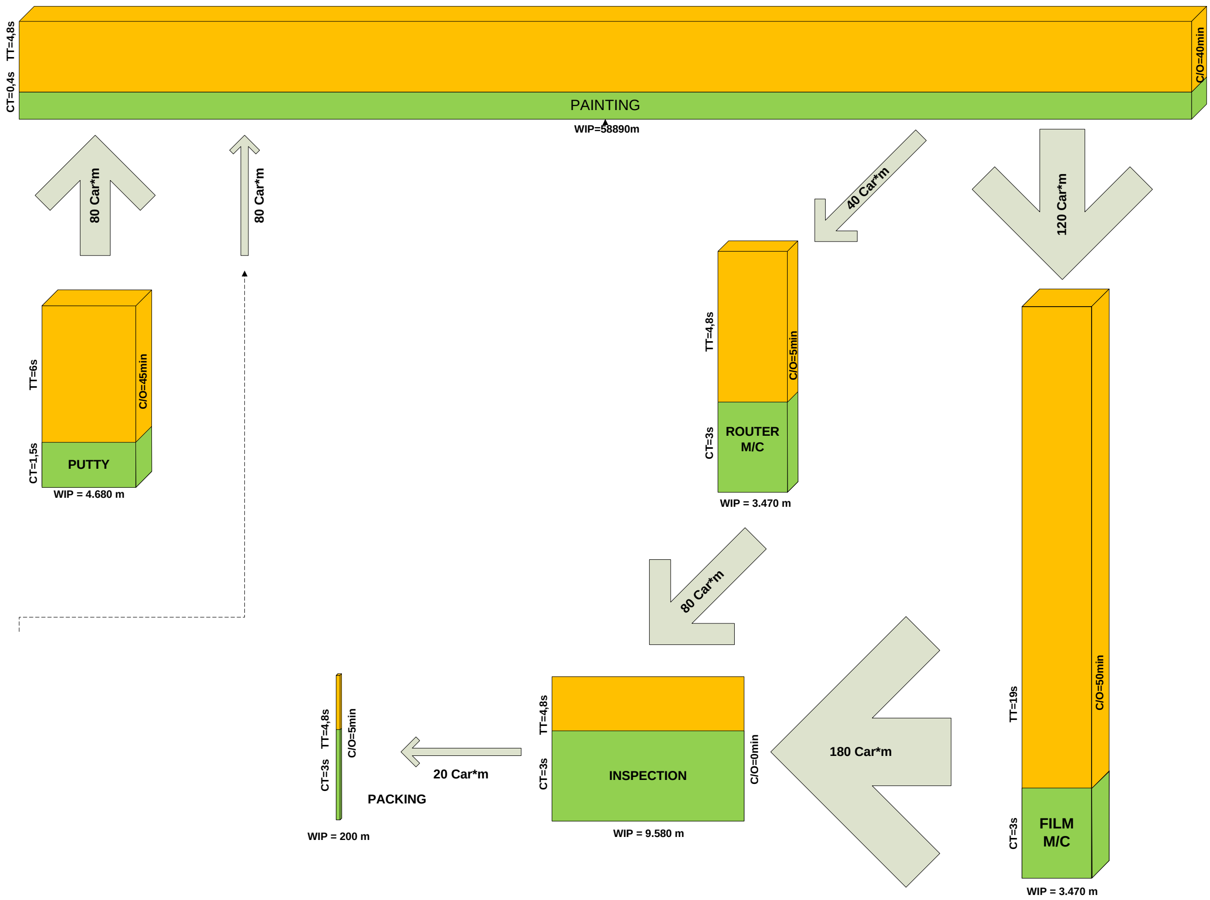

Fig 4. Example of a WID of a real production unit

Knowing that the icons' size is correlated to the level of the associated waste it may be stated, after a simple look at the diagram, that the PAINTING process is clearly the most critical spot in terms of inventory and throughput time. It can be said that there is a lot of waste associated to the painting process. The second most critical process in terms of throughput time is the FILM M/C, although with much less associated WIP. In terms of transport, it is also clear from a simple look at the diagram that the most critical spot is the transport from the FILM M/C process to the INSPECTION process, with an effort of 180 car*m per day. The PACKING process has very little amounts of WIP and some of the practices applied there could probably be replicated to other processes. Another class of information that comes clear on this diagram is the idle capacity available in all processes. Since the orange areas represent idle capacity we observe that most processes are clearly underused. These diagrams can also be used for continuous improvement, projecting future states for the diagram as it is done with VSM diagrams. In general terms it may be said that any action able to reduce the sizes of the blocks will result in better production performance. Another type of improvements can be obtained by undertaking actions that result in the reduction of the orange areas.

5. CONCLUSION

The concept of Waste Identification Diagram (WID) was presented in this paper along with its main features and advantages. These diagrams are able to describe production units with precious visual information enabling managers in the identification of the main forms of waste associated to the materials flow (inventory, overproduction and transport). The size of the areas and volumes are proportional to the production waste so it is easy to identify the locations of the most critical processes, i.e., with highest responsibility in generation of waste. Indicators such as throughput time, idle capacity, transport effort, WIP and changeover times are easily understood through a simple glance at the diagram. An example of a WID for a real production unit was also presented highlighting the main locations needing improvements.

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