"DMAIC FL_UE: application of revised tools for the study and optimization of materials flows in a metalworking company"

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Abstract: The improvement cycle DMAIC - Define, Measure, Analyze, Improve and Control - is a powerful framework that ensures a data-driven approach for improving, optimizing and stabilizing business processes and design phases. DMAIC suggests the adoption of standard and specific tools for each phase. In this work an improved methodology is proposed, called "DMAIC FL_UE". The term FL_UE means FLow_valUE, it is added to put the attention of the proposed approach to the Value Chain and to a particular tool: Value Stream Map. Consequently, the focus is on some of the 7+1 wastes of lean production, more linked to the material flow optimization. The DMAIC cycle can be divided into two parts: first three phases - DMA, "set the problem"; last two phases – IC, "solve" the problem. The main goal of the proposed methodology is the setting of the problem by the analyst, using the proposed tools. According to DMAIC FL_UE, traditional mapping tools have been reorganized and new ones have been proposed. In order to test the applicability of the new approach for highlighting the criticalities, a case study was developed in a company of the metalworking industry and the current state of material flows was analyzed through the use of the DMAIC FL_UE tools. It was possible to analyze the flows of raw materials and products, highlighting many critical issues to be solved and stages to be optimized; in particular: many unnecessary handling activities managed by internal suppliers; big quantities of materials ordered by internal planners; a very low digitization and integration of production information. Therefore, starting from the photograph of the actual process problems, possible solutions are suggested to the company in order to reduce the lead time and the storage of materials, that means to reduce the invested capital and to increase the elasticity and flexibility to satisfy the market demand. Subsequently, the company management should adopt the suggestions to solve the highlighted criticalities, monitoring the results in terms of flow optimization.

Keywords: Lean tools, materials mapping, handling and storage, flow value analysis.

Introduction

Material flows tell us a lot about how production is organized. Starbek and Menart (2000) studied the optimization of material flows in production and they understood that too high costs are a result of irrational and too long material flows in the production process. Therefore, it becomes important to identify the activities that absorb resources but don't create value, adding only time and cost. Nicholas (1998) found that waste takes many forms. Instead, Russell and Taylor (1999) define "waste" as anything over the minimum amount of equipment, effort, materials, parts, space and time that are essential to add value to the product. Lean Manufacturing (LM) is the systematic approach to identify and eliminate "wastes" (non-value added activities) through continuous improvement (NIST, 2000). Lean Manufacturing is based on the fundamental goals of Toyota Production System (TPS), which aims to minimize wastes and to speed up flows (Hines and Rich, 1997; Vinodh et al., 2010). According to TPS, the seven most common wastes are: overproduction, transport, waiting, inappropriate processing, unnecessary inventory, motion and defects (Ohno, 1988). More recently, another waste is considered: non-utilized talent, that means underutilizing people's talents, skills and knowledge (Jasti, 2015).

In this paper, we focused on the following four main wastes: transport, waiting, unnecessary inventory and motion. The idea is to suggest a new approach and revised tools to investigate the "stop and go" moments for materials along the process. The final objective is to propose an agile approach for projects of improving, to decrease the "stop" and increase the "go" of materials inside the company (Petrillo, 2018). Important improvements derive from the possibilities provided by Industry 4.0 technologies (Kolberg, 2015).

The article is organized as follows: the section one refers to the improvement cycle DMAIC; the section two introduces the proposed methodology called "DMAIC FL_UE". - DMAIC FLow_valUE". The section three is about the application of this new methodology in a mechanical company to analyze material handlings through many tools: flowchart, flow process chart, spaghetti chart, value stream mapping. The previous tools are customized and applied to the particular case-study, even if they are developed in a general way. The section four discusses the critical issues encountered and the proposals for their improvement. Conclusions and future developments complete the article.

1. DMAIC overview

To achieve the excellence in implementing LM in different organizations, many studies propose the use of various principles, techniques and tools (Jasti et al., 2012; Piercy and Rich, 2009); even if few researchers have proposed very new aspects (Anand and Koladi, 2010); while, many researchers have performed some revisions and integrations of well-known elements (Pettersen, 2009; Papadopoulou and Ozbayrak, 2005). Instead, in agreement with other authors (Shah and Ward, 2003 and 2007; Singh and Sharma, 2009), LM uses very often the same main tools and techniques: value stream mapping, 5S, kaizen, kanban, total productive maintenance, poka yoke etc., to identify and remove wastes from any process.

Value Stream Mapping (VSM) is one of the most powerful tools used in LM (Abdulmalek and Rajgopal, 2007). VSM is a technique for analyzing the flow of materials and the linked flow of information, based on the language of symbols (Jones and Womack, 2000). VSM is a graphic mapping of all the activities and stages that contribute to the realization of a product or service, starting from the supplier of raw materials up to the delivery of finished products to the customer; the technique also identifies all the value-added and non-value-added activities along the process (Rosentrater and Balamuralikrishna, 2006).

According to Monden (1993), there are three different possibilities for mapping activities:

(1) non-value adding (NVA);

(2) necessary but non-value adding (NNVA) or so called business value-adding (BVA);

(3) value-adding (VA).

The first type is pure waste and involves actions which should be eliminated completely. Examples are: waiting times, stacking of intermediate products and double handlings. Necessary but non-value adding operations may be wasteful but are necessary for the operating procedures. Examples would include: walking long distances to pick up parts, unpacking deliveries and transferring a tool from one hand to another. These types of operations can be eliminated but it would be often necessary to make major changes to the operating system such as creating a new layout, for example using simulation (Falcone *at al.*, 2013). Such changes may not be possible immediately. Finally, value-added operations are all the activities that involve the transformation of raw materials or semi-finished products. Those type of activities is simply recognized by the final customer, contributing to increase his satisfaction, therefore he pays for them. However, according to Bhamu and Sangwan (2014), to provide feasible solutions, LM requires the adoption of the DMAIC - Define, Measure, Analyze, Improve and Control - approach in applying the above tools, to map, improve and optimize the process. In agreement with De Mast J and Lokkerbol (2012), DMAIC is an effective problem-solving method in Six Sigma strategy; it provides a structured problem-solving procedure, and it is suitable for many tasks.

The present work proposes a methodology derived from the DMAIC cycle focused on the optimization of materials flow, in particular on “stop and go” moments along the process.

2. DMAIC vs DMAIC FL_UE

This work presents a methodology derived from the DMAIC cycle, called DMAIC FL_UE. The term FL_UE means FLow_valUE, it is added to put the attention of the proposed approach to the Value Chain and to a particular tool: Value Stream Map. That methodology starts from the study of the DMAIC cycle, derived from Deming’s PDCA cycle and divided into five sequential phases: Define, Measure, Analyze, Improve and Control. The DMAIC cycle is characterized by two parts: first three phases - DMA, “set the problem”; last two phases – IC, “solve” the problem. The core of the proposed methodology is the setting of the problem by the analyst, using data coming out from three different points of view.

2.1 Proposed methodology

DMAIC FL_UE focuses mainly on DMA: Define – Measure – Analyze, and consequently in “problem setting”. The more two phases: Improve and Control, linked to the subsequent solutions adoption, could be or not, depending on the outputs of the first phases and on the company management decision to go on. In the Improve phase - it will be possible to identify and implement all the improving actions. The Control phase can only take place at the end of the Improve phase, to sustain the obtained results.

Figure 1: DMAIC FL_UE focus

The core of the proposed approach is the focus only on some wastes of Lean Production (transport, waiting, unnecessary inventory and motion) and the innovation is a revisiting of traditional tools for mapping the process, qualitative and quantitative, in particular in the Analyze phase, to optimize materials flow and storage (Figure 1).

2.2 Problem setting phases

First phase: in the *Define* phase, the physical handling of materials is studied and the materials path mapped.

Second phase: in the *Measure* phase, it essential to make the transition from a simple descriptive/qualitative mapping to a quantitative one, necessary to indicate the number of moved handling units (e.g. boxes).

Third phase: the *Analyze* phase is the core of the proposal, in fact some tools more suitable for the objective were identified and their sequence of application. In particular, traditional tools were revisited and new upgraded ones proposed. In the table n. 1, there is a comparison between traditional and new tools, with some notes about the upgrading.

The proposed approach is represented in the figure n. 2.

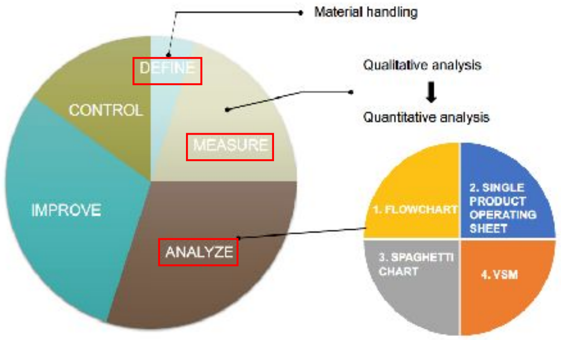

Figure 2: DMAIC FL_UE approach

Table 1: DMAIC FL_UE steps&tools

Sequence	Conventional tools	Innovative tools	Upgrade notes
Step 1	Flowchart	Revised Flowchart	Visual signals-different colors for material handling owners and information flow supports
Step 2	Single-product flow process chart	Revised Single-product flow process chart	Visual signals-different colors for VA-NNVA-NVA process phases
Step 3	Spaghetti chart	Revised Spaghetti chart	Visual signals-different colors for material handling owners and used means/devices
Step 4	Value stream mapping	Revised Value stream mapping	Visual signals-different colors for VA-NNVA-NVA time line levels
Step 5	---	Integrated dashboard	Integration of all the four steps/tools

3. Application in a metalworking company

The case study was carried out in one of the leader companies of products, solutions and services in the metalworking sector.

The analysis of material handlings focused on several areas that will be referred in following sections.

3.1 Materials flow analysis

In the following, the most significant examples of the DMAIC FL_UE application in the investigated firm, are showed, following the steps present in Table 1. The materials are identified in a generic way and three examples of the application of the proposed methodology and related tools are shown in the following: Product A and Product B-Type X and Type Y.

- Product A
  - Step 1

Product A comes into the plant and it is unloaded by the operators of external suppliers. Then a visual check is performed to verify if the content is complainant with the transport document, then the operators assign the products to the various work stations. Then, two cases are possible: the material is not necessary in production or it is. In the first case the material is directly allocated in the warehouse, in the second case the material is allocated in a buffer far about 20 m from the production lines. Those operations and information are represented in the figure n. 3.

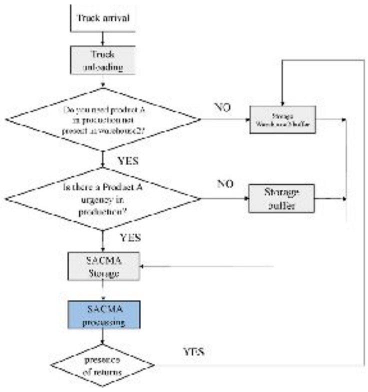

Figure 3: Example of revised flowchart – Product A

- Step 2

In the second stage, a revision of the single-product flow process chart is proposed. In particular, according to the classification of activities into VA; NNVA or BVA; NVA, in the sheet the different value of each activity is highlighted using different colors. In this way it is immediately evident where the problems are present along the process.

ITEM	Distance [m]	[min]/ride	ACTION	DESCRIPTION	OPER
	-	-		Truck arrival	
Product A	-	-		Waiting	Comp.K
Product A	-	60		Truck unloaded	Comp.K
Product A		10		Check	Comp.K
Product A	35	3		Transport to warehouse 2	Comp.K
Product A	-	-		Storage in Warehouse 2	Comp.K
Product A	60	3		Transport to buffer	Comp.K
Product A	-	-		Storage in buffer	Comp.K
Product A	20	2		Transport to Sacma	Comp.K
Product A				Storage in SACMA	Comp.K
Product A	-	-		Machine loading	Comp.W
Product A	-	-		Processing	Comp.W
Product A	70	3		Transport any returns	Comp.K
Product A	-	-		Storage in warehouse 2	Comp.K

Figure 4: Example of Revised single product flow process chart – Product A

In the figure n. 4 the sheet has been modified, highlighting the various types of operations with different colors, considering the ASME symbols. In particular, the good actions are represented in green (VA), the actions that should be eliminated in red (NVA), while the actions that are not VA and that could be reduced in yellow (NNVA or BVA). Product A arrives 2-3 times a month with non-scheduled trucks, so the following considerations refer to a single arrival, the period of observation was two weeks. Furthermore, the transport of the raw material (Product A) from the warehouse 1 to the processing buffer or to the pull stand, doesn't take place daily but according to specific requirements.

- Step 3

The starting point is the collection of data of all handling activities from one point to another inside the firm, also information about responsibilities/different involved operators and means/devices; then the representation of them on the layout of the plant is possible (Figure n. 5).

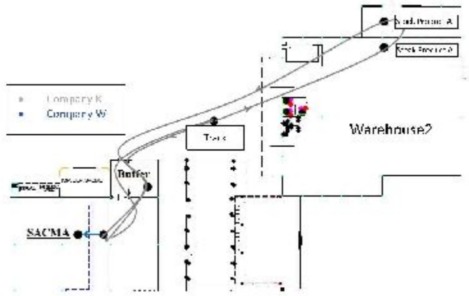

Figure 5: Example of revised Spaghetti chart – Product A

At the beginning of the analysis only a qualitative spaghetti chart was possible to draw, because the available data on the number of boxes were insufficient. Therefore, it was necessary to define data entry supports to collect more information to shift from a qualitative spaghetti chart to a quantitative one, called weighted spaghetti chart as showed in the following example.

- Step 4

Finally, we drew the value stream mapping, starting from the current state of the process. In the same way of the revised single-product flow process chart, in the construction of the Lead Time ladder at the bottom of VSM, three different colors and levels are used to show VA; NNVA or BVA; and NVA activities (respectively green; yellow and red).

The revised VSM of Product A is represented in the figure n. 6.

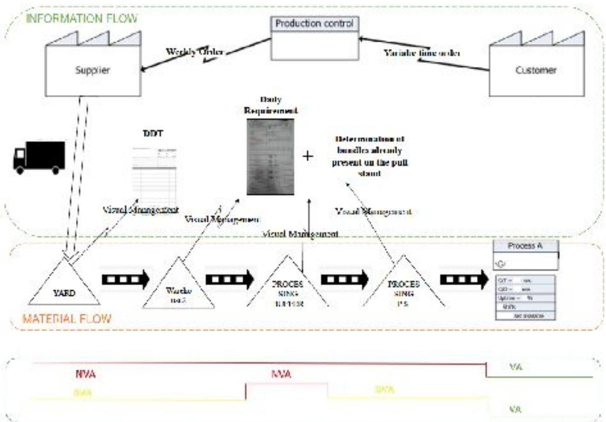

Figure 6: Example of Revised Value stream mapping – Product A

According to the traditional two-levels analysis (upper Time Line ladder at the bottom of VSM in the figure n. 6), it is possible to note that the only value-added action is given by the process box of the product. Instead using the three-levels analysis (lower Time Line ladder at the bottom of VSM in the figure n. 6) it is possible to carry out a deeper knowledge of the process. So, the storage in the pull stand is a non-added value action, but it turns yellow because this action cannot be avoided without modifying the plant layout. The non-value-added operation are the storage of intermediate products before going to the processing pull stand, in an intermediate warehouse - the buffer – with picking actions to be brought to the pull stand only when necessary. This operation is almost useless, it could be eliminated to facilitate the straight transition between warehouse and pull stand.

- Step 5

Finally, it is useful combining all the above tools in a unique prospective, called Integrated dashboard (Fig. 7).

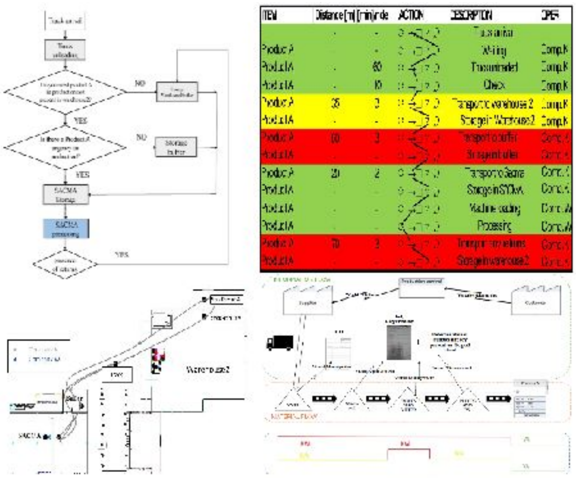

Figure 7: Example of Integrated dashboard – Product A

In the following the application for another product is showed, with more criticalities (Figure 8).

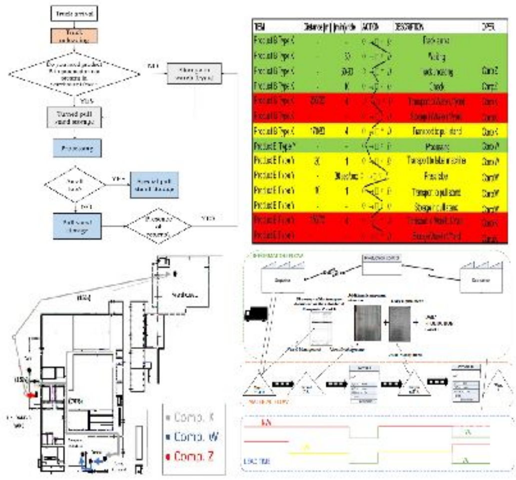

Figure 8: Example of Integrated dashboard – Product B

4. Critical issues and proposals

Thanks to the application of the proposed approach and tools, many critical issues have been identified. Those critical issues should be solved in order to realize an optimal management of material flow and storage. But, after the ending of the problem setting stage, through the DMAIC FL_UE execution, the solving phase can start or not, on the basis of the previous results and according to the company management decisions. In particular, for the analyzed case study, the main results were:

- **Returns.** The forklift drivers of the companies K and Z carry out empty transports, even if in limited numbers; this aspect causes a flow that is not optimized. Those operators move into the direction opposite to the main flow, towards the warehouse 1 and the unloading area. These returns are characterized by a low payload or often null, causing totally useless handling acts.

- **Intermediate buffer.** The corridors and the warehouse 2 are the areas with less material, they could be used as buffers, in particular of Product A. In fact, by avoiding the transit towards that processing buffer, the time spent in useless handling acts can be avoided.

- **Materials placed in the unloading area.** We observed a particular situation for Product B: the warehouse 1, where it should actually be located, is sometimes full and there is not enough space. For this reason, the operator of the company K is forced to place Product B "temporarily" inside the arriving yard (until the space in the warehouse 1 is created).

- **External suppliers inside the firm.** The use of operators of external suppliers makes the plant highly dependent on them. On the other hand, the external suppliers operating inside the firm are not aware of multiple aspects that determine an optimal functioning of the company itself. For example, they are not aware of the real stock of the material inside the warehouses, in particular in the warehouse 1. Then, if the activity of those operators has suddenly to stop, this would have many consequences and would have a significant impact on the production. The material present in the warehouse should be easily identifiable and easily manageable. The company must be aware at all times of the exact position of all materials thanks also to the adoption of new software tools.

- **Lack of information.** The operators often use only a material visual management. Starting from the counting of the boxes in the pull-stand, up to the control of all materials that arrive every day. This task is assigned to a single person with wastes of time; moreover, the human labor is easily subject to error; therefore, an appropriate digitalization process is necessary, adopting new solutions, also provided by Industry 4.0 technologies.

5. Conclusions

In the present work, starting from Flow Value Analysis, an integrated methodology has been proposed and applied within a metalworking company, called DMAIC FL_UE. In particular, the application allows studying material management problems from different perspectives. Revisited graphical tools to optimize the flow and storage of materials have been developed. Both physical flows of materials and information flows are investigated, linked to all the movements of the materials and their storage. Consequently, Non-Value Added activities, Value Added activities and also Business Value Added activities were highlighted thanks to the proposed tools. The adoption of some graphical tools joined together to analyze problems, makes the methodology very powerful to suggest possible solutions for optimizing the management of materials. Continuing the methodology development, the future step could be the adoption and revisiting of other different tools, for example for dimensioning pull stands, according to the previous analysis and through the application of Little's law.

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