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► **To cite this version:**

Rainer Schillig, Timo Stock, Egon Müller. Energy Value-Stream Mapping a Method to Visualize Waste of Time and Energy. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2015, Tokyo, Japan. pp.609-616, 10.1007/978-3-319-22756-6_74 . hal-01417624

HAL Id: hal-01417624

<https://hal.science/hal-01417624v1>

Submitted on 15 Dec 2016

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Energy Value-Stream Mapping a Method to Visualize Waste of Time and Energy

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Abstract. In the industry, the Value-Stream Mapping (VSM) method has been successfully used for years to reduce inventory and lead times. With this method, process steps in a value-stream can easily be divided into value-adding and non value-adding ones. However, the VSM does not provide any information about the energy consumption and, as a consequence; it does not give any hint at how much of the energy used actually serves value-adding purposes. This paper describes how the VSM can be extended to an Energy Value-Stream Mapping (EVSM) method which allows dividing the energy input of the production process in value-adding and non value-adding.

Keywords: Energy Value-Stream Mapping · Energy Efficient Production and Logistics · Lean and Green Production · Toyota Production System

1 Introduction

While the manufacturing industry is one of the main energy consumers, it is at the same time also the key factor for our prosperity. Considering the continuously rising energy cost and an increasing public awareness of the need for a sustainable economic activity, many branches of industry have declared energy efficiency their strategic business objective [1].

In Germany for instance, during the second half of the last century, labour productivity has increased almost fourfold, while energy productivity has not even doubled during the same period of time [2]. In the past, the industry's rationalizing efforts have focused on increasing the degrees of automation while simultaneously cutting down the cycle times.

When in the nineties of the last century the methods of the Toyota Production System (TPS), with its focus on systematical waste reduction came to be known in the Western World, numerous companies tried to adopt them for their own use. Since that time the TPS is considered as a benchmark for creating highly efficient value-streams and often it is also described as a lean production system [3].

2 The Toyota Production System

Taiichi Ohno, who is one of the TPS's architects, described its essence as follows: 'All we are doing is looking at the time line from the moment the customer gives us an order to the moment when we collect the cash. And we are reducing that time line by removing the non value-added wastes' [4], Figure 1.

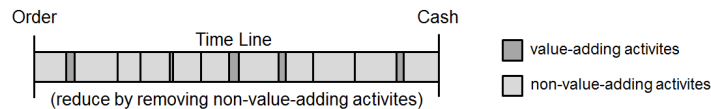


Fig. 1. Essence of the TPS according to [4]

Thereby he makes it quite clear; the point is to reduce non value-adding activities and not regarding details of the value-adding. To identify non value-adding processes for the first, Ohno divided activities into waste and work, Figure 2. To identify waste systematically, Ohno named 7 types of waste. Work usually consists of a combination of value-adding and non value-adding activities.

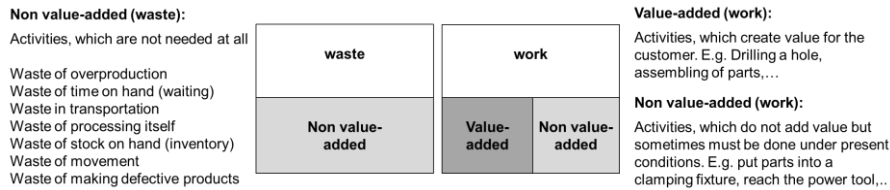


Fig. 2. Value-adding and non value-adding activities according to [4]

3 Value-Stream Mapping and Energy Value-Stream Mapping

Rother and Shook [5] presented in 1999 a method called Value-Stream Mapping which was apt for practical use. This method made it possible to look at the cycle times of work separately from the non value-adding lead time (waste). In their approach, minimizing the lead time extending inventory (waste) was the focus.

This approach may convey the impression that the process sequences within the cycle times (work) is, as a matter of principle, free from waste. However, this is not true. When taking a closer look, one can see almost always that the cycle time, of the manufacturing process itself, is composed of value-adding (t_{va} = time value-adding) and non value-adding (t_{nva} = time non value-adding) amounts of time [6].

There are several proposals in order to extend the VSM to an Energy Value-Stream Mapping (EVSM) [7-13]. Most of these approaches use a stepped 'energy line' to visualize the energy consumption alongside the process chain. The Environmental Protection Agency (EPA) [7] introduced EVSM by presenting the energy usage for each production step. Erlach and Westkämper [8] added two figures: The 'Energy Intensity' to describe the process-related energy consumption and the 'Degree of Effi-

ciency' to evaluate the process efficiency in comparison with a benchmark process. Reinhart et al. [9] demonstrated in their approach how different forms of energy like electrical, gas or compressed air could be visualized. [8, 9] formulated guidelines to improve the energy efficiency of the value-stream called Energy Value-Stream Design. Shahrabaki and Jackson [10] described in principal that energy in an EVSM should be divided into value-adding and non value-adding portions. They lack to explain how this could be done. Plehn et al. [11] extended the representation of the EVSM by an input/output model using the criteria energy, materials, water, waste and emissions. Posselt et al. [12] added the process related energy consumption of peripheral systems. Keskin and Kayakutlu [13] showed the link between Lean and energy efficiency and the effect of non value-adding time in terms of energy waste.

However none of these proposals is built on an exclusively dual assessment of the time and energy input only referring to the criteria value-adding or not. If the VSM should be extended to an EVSM regarding the energy consumption of the production processes the cycle times must not be regarded as completely value-adding automatically.

Aalen University of Applied Sciences, in cooperation with Chemnitz University of Technology, has developed a method, called 'Dual Energy Signatures' allowing for appraising the process-related energy consumption using the criteria 'value-adding' and 'non value-adding'. This dualised approach allows extending the proven VSM method to an EVSM, in accordance with the principles of the TPS. The classification of energy into E_{va} (Energy value-adding) and E_{nva} (Energy non value-adding) opens up the possibility to divide the cycle times doubtless into t_{va} and t_{nva} , too.

4 How to Create a Dual Energy Signatures of a Milling Process

In the Aalen University's milling laboratory experiments were taken on a 3-axis vertical machining centre, Hermle Type C 30 V. The machining process consisted in successively milling three grooves of different widths into a component made from heat-treated steel. Milling was done in full cut, with an infeed of 7.5 mm over a distance of 60 mm and using three HSS end mill cutters with diameters 8, 12, and 16 mm. In parallel, a power measurement was taken [14].

To identify the energy, required for the actual chip removal, the authors suggest: Comparing the energy consumption while processing (the workpiece) to a material with a very low density (air). Therefore the test set-up had a distinctive feature in so far as the first pass took place using an 'air cut', in other words processing without a workpiece, Figure 3 - top. Thereby the production parameters should be maintained.

This made it possible to see what the energy signature of the process looked like without any workpiece contact. The second pass took place with workpiece contact, Figure 3 - center. When both signatures are overlaid one gets the dual energy signature Figure 3 - bottom. In this signature the value-adding elements of the process are clearly distinguishable, with regard to the input of energy as well as with regard to their duration, and can be differentiated unmistakably from the non value-adding elements of the process.

possible to do an air cut, due to technical limitations, the energy required for the chip removal itself can also be calculated. Appropriate approaches are [15, 16]. Thereby a dual energy signature can be drawn as well.

5 Dual Resolution of cycle time and energy input

The value-adding efficiency of the process in terms of energy, as well as in terms of time, can now be defined as η_{Eva} and η_{tva} , equation 1, 2. Therefore the value adding energy is divided by the total energy consumption of the process [1, 6, 14].

$$\eta_{Eva} = \frac{E_{va}}{(E_{va} + E_{nva})} \quad \eta_{Eva} = \frac{10Wh}{(10Wh+116Wh)} = 8\% \quad (1)$$

$$\eta_{tva} = \frac{t_{va}}{(t_{va} + t_{nva})} \quad \eta_{tva} = \frac{25s}{(25s+135s)} = 16\% \quad (2)$$

The use of dual signatures allows evaluating the production process in respect to the efficient usage of time and energy. The cycle time itself as well as the energy used within this cycle time is thereby consequently subdivided into value-adding and non value-adding parts. In the data box of the milling process the results are shown nominally, in form of figures, as well as proportionally in form of the bars beneath, Figure 5.

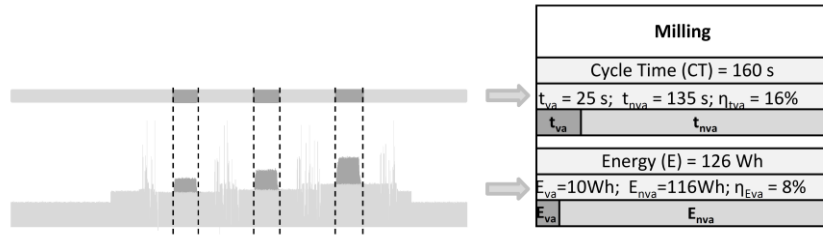


Fig. 5. Dual signature and data box according to [6, 14]

The low efficiencies show that the dual approach can help to reveal substantial improvement potentials within the production process itself. To increase the process efficiency, basically two approaches are possible: One is to decrease the power level and thereby reducing the non value-adding energy (E_{nva}). This affects just the energy productivity. The other one is the reduction of non value-adding time (t_{nva}). That will lead to an increase in productivity and in addition to energy savings. When time is wasted and during this time energy is consumed, this amount of energy necessarily also has to be regarded as waste, too. Up to now the authors have analysed several production processes like milling, casting, welding, injection moulding, handling, robotic and laser applications [1, 6, 17, 18]. For all of them a dualistic approach can be made. Other production processes are actually under research.

6 Energy Value-Stream Mapping

The analysis of the manufacturing process by means of dual energy signatures allows it to extend the VSM to an EVSM while maintaining the inner logic of the VSM [1]. The results of the investigated milling process are embedded into the EVSM, Figure 6. A drilling process and the time and energy used for the transport between the production processes are added (assumed figures). Transport requires almost always energy, has a lead time extending effect and is not value-adding. Consequently the time (t_T = time Transport) and energy (E_T = Energy Transport) used for transport are considered as non value-adding. This is schematically shown by the rectangular function, Figure 6.

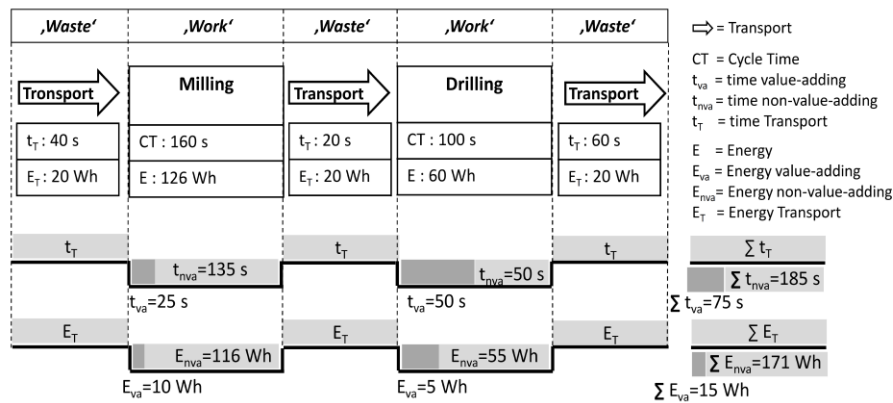


Fig. 6. Energy Value-Stream Mapping [according to 1]

As mentioned earlier, only t_{va} serves value-adding purposes, t_{nva} and t_T do not. On the right hand side of the time line the sums of these times are visualized. The same logic can be applied to the use of energy in EVSM. When optimizing energy value-streams it is important to look at the value-stream as a whole, this helps to avoid sub optimisations.

If there are processes which consume lots of resources (time, energy) or entail low value-adding efficiencies they should be seriously questioned in total. Only if it is impossible to find a more efficient manufacturing technology and a more suitable process, then as a second step the time and energy input which does not contribute to adding value can be reduced systematically.

7 Process Improvement by Dual Energy Signatures and Detailed Process Analysis

Electric energy (E) is the integral of power (P) over time (t). To increase the process efficiency, basically two approaches are possible: Reducing the process time or decreasing the power level [17]. However this requires detailed process knowledge and an analysis of all major components to allocate waste of energy.

Figure 7 shows the principal approach to improve the process efficiency by dual energy signatures and detailed process analysis. Like in figure 4, the value-adding time and energy, required for chip removal, are marked. From the point of view of energy only shares of the spindle and axle drive serves value-adding purposes. They drive the chip removal. As shown in figure 7 all the other components do not serve value-adding purposes. Especially the energy consumption outside the value-adding time should be questioned – eliminated. Therefore stop and go systems for the different components should be installed, e.g. for lightning, control cabinet cooling, etc. If complete elimination of the energy consumption in non-value adding periods of time is not possible it should be at least reduced to a minimum.

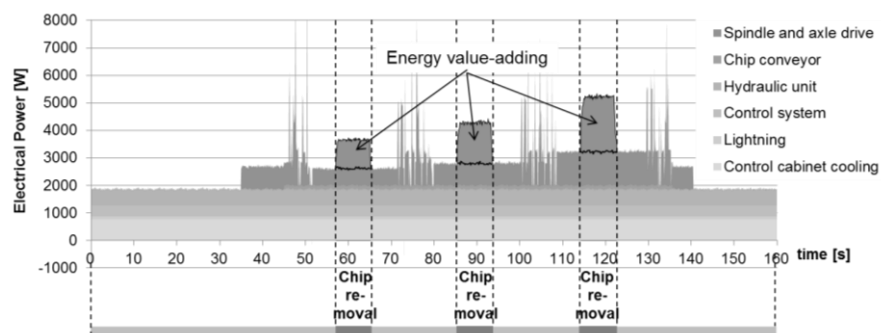


Fig. 7. Detailed Process Analysis

This mythological approach provides a systematic to identify and question any kind of wasted time and energy.

8 Summary

Value-streams that include time and energy data are becoming more and more important in the manufacturing industry. With the help of dual energy signatures the value-adding and the non value-adding inputs of time and energy within a production process can be determined, as desired by Ohno. This is shown by using the example of a milling process, in which the energy requirement during air cutting is contrasted with the energy requirement for a milling process with workpiece contact.

This distinction makes it possible to extend a VSM to an EVSM. Including transport in the EVSM offers the opportunity of visualizing not only its non value-adding energy requirement but also its lead time-extending effect. This methodical procedure provides a practical tool to process designers for a comprehensive analysis and improvement of value-streams.

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