Andrew Y.C. Nee, Bin Song, and Soh-Khim Ong (Eds.)

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Editors
Prof. Andrew Y.C. Nee
Mechanical Engineering
National University of Singapore
Singapore

Prof. Soh-Khim Ong
Mechanical Engineering
National University of Singapore
Singapore

Dr. Bin Song
Institute of Manufacturing Technology
(SIMTech)
Singapore

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Multi-Layer Stream Mapping as a Combined Approach for Industrial Processes Eco-efficiency Assessment

E.J. Lourenço[1], A.J. Baptista[1], J.P. Pereira[1], and Celia Dias-Ferreira[2]

[1] INEGI - Institute of Mechanical Engineering and Industrial Management, Campus FEUP, 4200-465, Porto, Portugal

[2] CERNAS – Research Center for Natural Resources, Environment and Society, Campus da Escola Superior Agrária, Bencanta, 3040-316, Coimbra, Portugal

Abstract

Nowadays achieving sustainable development is a global concern. The issue of unsustainability can be related to population growth and excessive consumption of natural resources. To tackle these issues, several management tools and methodologies have been developed in the last years, to assess, analyse and improve the environmental and economic performance of production systems. This work presents an approach based value stream mapping in order to assess and improve energy efficiency, environmental performance and financial performance of a production system. The developed approach can be applied to any industry or production system, where all the unit processes involved are identified and the inputs/outputs of each unit system quantified and easily perceived. Key environmental performance indicators and the corresponding eco-efficiency ratios arise as outcomes of this approach, in which a Multi-Layer Stream Mapping (MSM) with visual management attributes is created.

Keywords:

Multi-Layer Stream Mapping; Eco-efficiency; Value Stream Mapping; Performance Indicators; Visual Management

1 INTRODUCTION

In the whole history of mankind, sustainability was never as meaningful and important as it is nowadays. This fact collides with population growth; the scarcity of resources and their rising prices; the national and international environmental policies becoming stricter [1]. However, measuring sustainability and assessing sustainability evolution is an ambiguous and difficult task. In the 90's the World Business Council for Sustainable Development (WBCSD), established a framework to assess eco-efficiency, which embraces the economic and environmental dimensions, leaving out the social dimension that is part of the sustainability structure [2]. The WBCSD identified the following elements of eco-efficiency:

1. Reduce material intensity
2. Reduce energy intensity
3. Reduce dispersion of toxic substances
4. Enhance recyclability
5. Maximise use of renewable resources
6. Extend product durability
7. Increase service intensity

The purpose of eco-efficiency is to maximise value creation and minimize environmental burdens [3]. Eco-efficiency measures the relationship between economic growth and environmental pressure, and is generally expressed by the ratio between economic value and environmental influence, represented by:

$$\text{Eco-efficiency} = \frac{\text{Product or service value}}{\text{Environmental influence}} \quad (1)$$

Equation 1 - Eco-efficiency Ratio [3]

Eco-efficiency, as a management philosophy, has been adopted by many companies, including major economic groups such as 3M, Dow Chemicals, Toyota, BASF, etc. [2]. These companies believe that eco-efficiency goes a step further then corporate responsibility, and by embracing an eco-efficient mind-set, the outcomes are an asset for the company. For example, Toyota uses an approach based on environmental values, which reinforces their competitiveness and improves their eco-efficiency performance [4].

The framework developed by WBCSD can be used by any business to assess and measure progress towards economic and environmental sustainability [3].However, this framework lacks a simple and discrete approach in order to analyze and assess unit processes that are part of the production system.

The goal and main focus of this work is to present a combined use of an alternative tool, Value Stream Mapping (VSM), and demonstrate its suitability to assess environmental and energy performance of unit processes and production systems in a fast and flexible manner. This approach can be both very practical and useful for:

- Top management decision support
- Defining priorities
- Identifying inefficiencies in an easy manner
- Identifying Key Environmental Performance Indicators (KEPI)
- Assessing eco-efficiency performance
- Identifying improvement actions

Secondly, this work attempts to demonstrate the importance of presenting environmental issues and eco-efficiency performance in a simple manner, through visual management maps and layouts, in order to simplify top management understanding of the KEPI's and their suitability for decision making and overall awareness.

2 APPROACH

There are several methods, management tools and decision support approaches that aim to maintain or increase production while reducing costs, raw materials consumption, energy consumption, the amount of emitted effluents, waste generated, etc.

However, this paper presents a framework that combines Value Stream Layers (from Value Stream Mapping assessment) with visual management attributes, thus transforming the concept and the understanding of eco-efficiency into something more quantifiable, simpler, concise and directly applicable to any production system or process sequence.

This need arises since the existing eco-efficiency tools and methods are not always directly applicable to every product and/or production system, and often addressed as “isolated stage analysis”.

The other reason that sustains the need of such approach is related to the lack of fast visual management attributes in most methods and tools used for eco-efficiency assessments.

Visual communication is an important aspect for any management board or project manager, managerial esthetics highlights the critical roles of visual elements in modern management [5].

Therefore, the approach presented by this work presents the data and performance results in a fast assessable visual format. The outcome and results are diagrammatical and intuitive representation of managerial concepts. This helps to amplify cognitive ability or reduce complex cognitive work, consequently humans can derive better and faster the overview information, than if presented in a textual/numerical format [6]. Spatial positions or colors provide similarity amongst different features than do texts or numbers, which is one of the key reasons why human beings can be visually attentive to certain symbols and identify visual patterns [6].

Thereby, in order to fulfill the visual management attributes, the Key Environmental Performance Indicators and the global performance results are represented in Dashboards, thus taking into account that the primary purpose of a dashboard is to display all of the required information on a single screen/layout, clearly and without distraction, in a manner that can be quickly and objectively assimilated by top management, stakeholders and project managers thus allowing them to see the necessary information at a glance and make an informed decision [7].

The combined use of Value Stream Layers of a Value Stream Map emerges in order to “see beyond” the global environmental and financial performance of a production system in a simpler manner and enables the understanding of the eco-efficiency assessments, and at the same time simplifies the identification and quantification of specific inefficiency situations.

In order to assess the environmental, financial and global performance of a production system and also identify and quantify the inefficiencies and misuses, this framework starts from the classic bathtub curve of Value Stream Mapping.

Value Stream Mapping

The Value Stream Mapping (VSM) approach adopts a flow perspective rather than an activity-based perspective on how work gets done (Figure 1). It includes metrics to gauge certain types of waste/inefficiencies in the supply chain [8, 9].

According to Rother and Shook’s approach [10], a value stream consists in the collection of all actions (actions that add value and actions that don’t) that are required to bring a product or a group of products through the main flows, starting with raw material and ending with the customer [8, 11]. To map a value stream, the first step is to choose a product family as the target for improvement and then map its current state (while walking along the current production system). In other words, it consist in capturing a snapshot of how thing are actually done, consequently creating the current state map. The following step is to create the future state map, which is a picture of how the system should look after the inefficiencies in it have been removed [8, 11, 12].

The primary goal of this tool is to identify all types of waste in the value stream flow and processes in order to take actions to try and eliminate these, by analyzing the Value Stream Maps (VSM) [9, 11].

Kuhlang and Edtmayr [9] have studied the application and use of an extended value stream map (Figure 2), although their extended stream map does not consider multiple aspects of different nature (as for environmental, economic and global performance aspects). Their goal was to reduce lead time (wastes) by using an extended value stream map that also considers, for example, the area occupied by each machine or industrial element.

The lean tool here presented arises in this framework because it can be a practical and useful way to identify actions that do not add value to the final product and to identify inefficiency and wasteful situations. In this approach, Value Stream Maps are used to quantify in detail not only the time spent but also to identify: costs, emissions, energy consumption, resource consumption, waste generated, etc., of all unit processes. Unlike the usual VSM that just maps out individual process times and stocks, or areas and transport in the extended version by Kuhlang and Edtmayr [9], the idea here is to assess overall eco-efficiency performance, using a VSM bathtub curve for each environmental and financial aspect, or any kind of variable, originating a Multi-Layer Stream Mapping (MSM) for overall performance assessment.

The ratios and key performance indicators can be easily quantified in terms of: consumption of energy and resources, emission, waste generated and costs of each unit process, allowing the user to calculate the efficiency of utilization of various resources and production time. This facilitates the task of identifying improvement actions that are necessary or which can be implemented. This approach also helps to better understand how the production system interacts along its sequence.

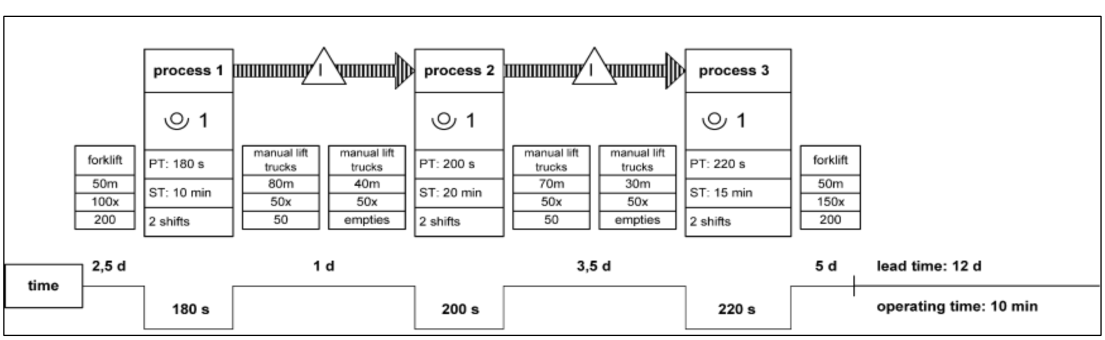

Figure 1: Common Value Stream Map for production time assessment [9].

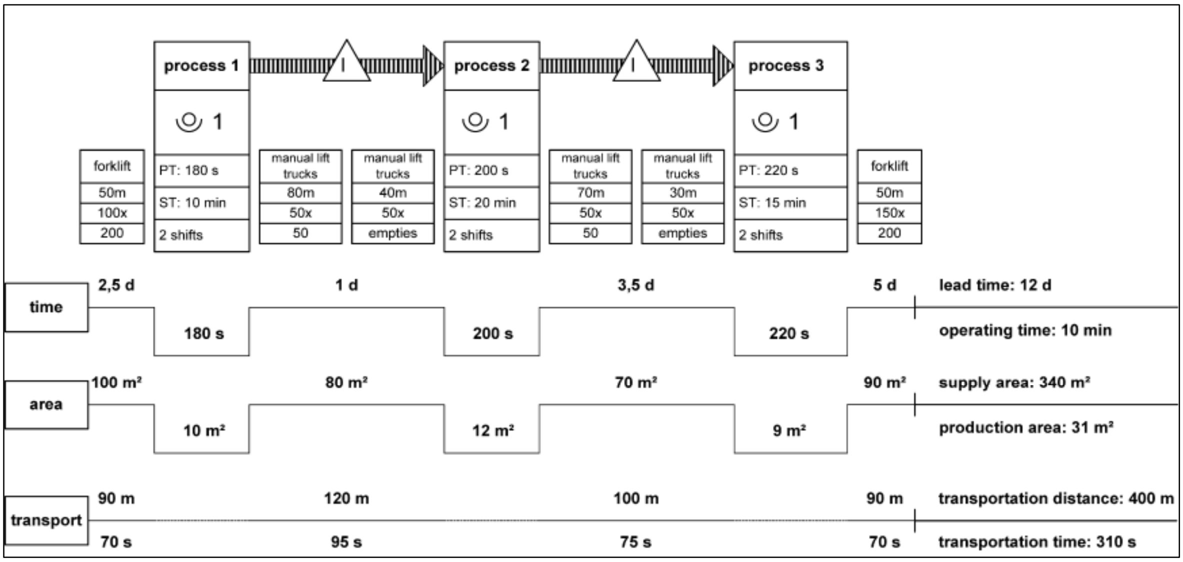

Figure 2: Extended Value Stream Map [9].

3 MULTI-LAYER STREAM MAPPING DESCRIPTION

The Multi-Layer Stream Mapping (MSM) consists in replicating the approach used for Value Stream Mapping, but allowing the addition of multiple layers (stream flows) that embrace environmental and economic aspects, or other key variable, in order to assess eco-efficiency performance.

Figure 3 characterizes an example of the application of the MSM approach.

The values located below of the MSM line are those which do not add value to the product (Lead Stages), i.e. representing the "waste/misuses" of time, money or resources. On the other hand the values that are presented above the VSM line (Process Stages) are those that add value to the product, thus representing the "useful consumption" of stream flow that can be analyzed in order to assess, evaluate and quantify production efficiency and eco-efficiency performance aspects.

One key feature of the MSM approach consists in considering dimensionless ratios, so the higher the result for the ratio, the better the performance of the energy, mass or time flow or other key variable of a process or system. It should be noticed that the MSM approach can assess, quantify and analyze environmental aspects (energy consumption, emissions, raw material consumption etc.), economic aspects and productions aspects one by one. This is possible if the stream under analysis follows in the direction of the processes stream (raw direction in the diagram), the final result of the stream variable metric will be represented by φ (Figure 3).

Besides assessing individual streams, it is also possible to quantify the efficiency performance of unit processes (P_1, P_2, P_N), by following the Multi-Layer Stream Mapping direction P_1 φ (column direction of the diagram in Figure 3).

Finally, the overall efficiency of a process sequence or system can be evaluated by calculating the average (or other weighted formula) of the several φ of the processes. This evaluation is again possible since the results of each φ, of each process, are dimensionless.

The results of φ in both directions (Process Stream Analysis and Multi-Layer Stream Mapping) are Key Performance Indicators. Therefore by analyzing and mapping environmental aspects as streams, the outcome is a Key Environmental Performance Indicator. The process variables that can be assessed according to this approach are unlimited. For instance, the following environmental aspects can take place as assessing variables:

- Energy Consumption
- Raw Material consumption
- Fuel Consumption
- CO_2 Emissions
- Waste Generation
- (…)

Beside these environmental aspects, other specific cost flows can be added, i.e. a cost flow to assess the costs of energy consumption only, or raw material only, thus allowing to assess specific eco-efficiency indicators (since product value and environmental influence are specific).

The eco-efficiency performance can be evaluated, by following the Multi-Layer Stream Mapping direction (column direction of the diagram in Figure 3). This approach provides a wide range of eco-efficiency evaluation data, due to the possibility of assessing the eco-efficiency performance of a process stage that adds value to the product (Figure 3 - equation (a)) and/or asses the eco-efficiency performance of the stage that does not add value (Figure 3 - equation (b)). The global eco-efficiency performance of a process can also be assed (Figure 3 - equation (c)). It's worth mentioning that when assessing global eco-efficiency performance several environmental aspects (Environmental Influences) can be added to the denominator of the equations (c),(f) and (i) in Figure 3, in turn the overall eco-efficiency performance of the process will arise as an outcome of this approach.

Multi-Layer Stream Mapping Features

In order to facilitate the identification of major inefficiencies and assess, evaluate and quantify eco-efficiency performance, visual management interpretation for each unit process is highlighted according to their efficiency score (Figure 4).

The global efficiency performance of the process is presented by highlighting only the main process flow and omitting the bathtub lines in order to present a final MSM dashboard in a simplified way and in an even more understandable manner (Figure 5).

For the color labels four classes were considered. The first efficiency class represents the range from 90% to 100% (green highlight); the second efficiency class from 70% to 90% (yellow highlight); the third from 40% and 69% (orange highlight); and the final efficiency class is for less than 40% (red highlight). It is noteworthy to emphasize that the yellow and orange classes have a variation of approximately 50%, while the green class has a variation of 10% (see Figure 6).

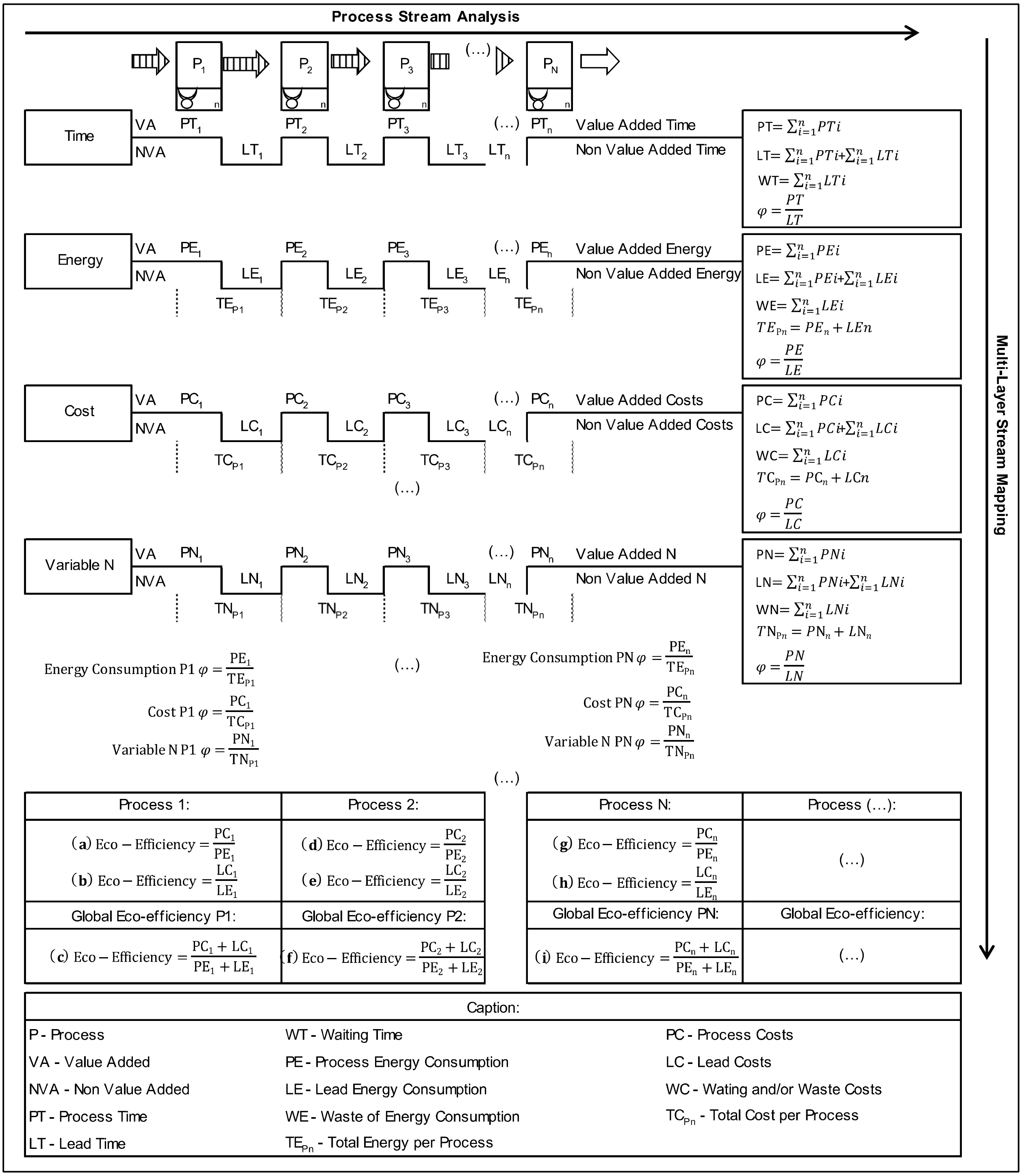

Figure 3: Multi-Layer Stream Mapping Approach.

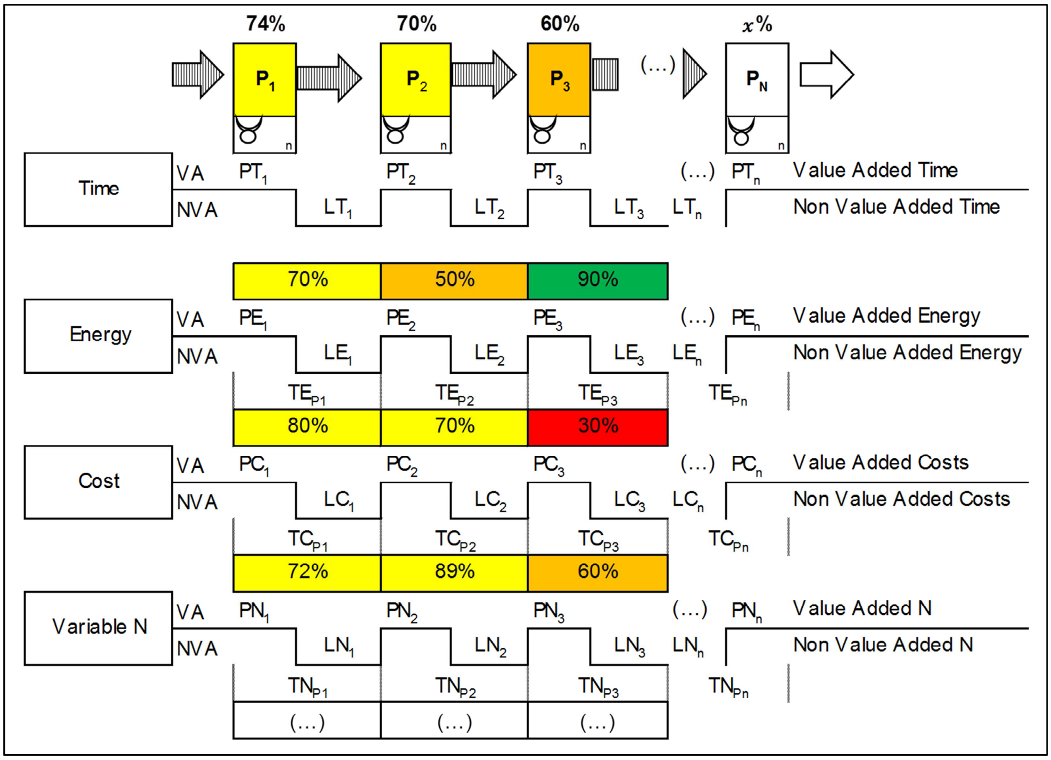

Figure 4: Global efficiency dashboard (Example).

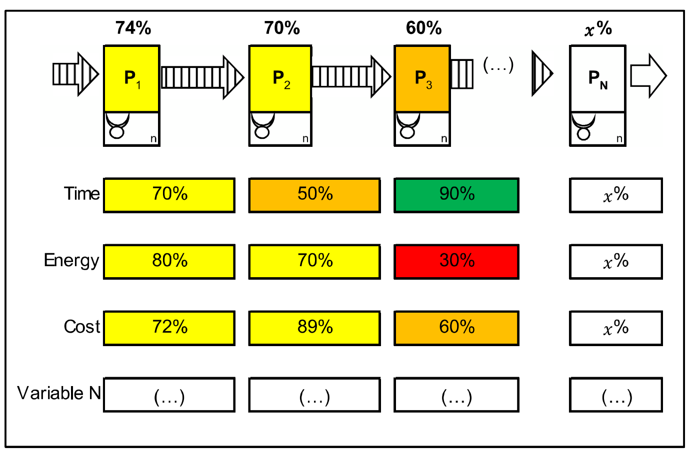

Figure 5: Final efficiency dashboard (Example).

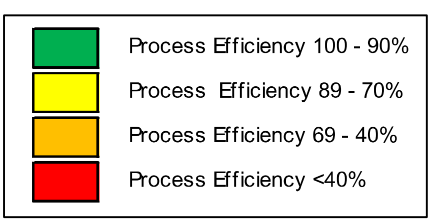

Figure 6: Color labels ranges for the MSM diagram.

Figure 4 is a schematic output of this approach that can be used to assess and evaluate both data and key performance aspects. The identification of KEPI takes place by assessing the results of the global efficiency dashboard, in which these key indicators are represented by the total value of each process, in each stream (i.e. TE_{P1}, TE_{P2}, TC_{P1},TN_{Pn} as presented in Figure 3). The final efficiency simplified dashboard (Figure 5) represents the efficiency results for each process and layer stream, as it can also represent the overall color indicator for each variable and for the overall industrial process sequence. The results obtained in each stream represent, in the presented case, an average value of the efficiency for each unit process, and this is determined by the overall average value of each unit process taking into account all streams related to the process.

Another relevant aspect is that in this approach all inefficiencies and misuses are accounted in the non-value added stages. Usually these stages represent transportation time or pauses during productions. Therefore, when using the MSM approach, transportation data should be added to the other misuse/waste data in order to properly assess the efficiency of a transportation process. In that case, if the goal is to know with greater accuracy the transportation efficiency, then one should add another layer stream (by adding a new variable) or by drilldown the MSM approach (Figure 7).

4 APPLICABILITY AND STRENGTHS

The MSM approach, like the traditional VSM, can be used to identify which processes and/or streams are less efficient, thus contributing for decision support and allowing continuous improvement to environmental and financial key performance indicators.

This approach can also be used for process reengineering evaluation, since in some cases the unit processes, or even the whole production system of a factory, have good operational results, but the efficiency is not as high as it could be. Therefore, using this approach to scrutinize "how", "where", and "how much" can a unit process and/or a production system improve its financial, environmental and performance aspects, is of great importance for decision-making.

A drilldown approach of the MSM can be executed, as cited before, in order to, for instance, assess and identify inefficiencies and misuses that occur along a production system, at a unit process or in one particular stage of a production system.

One other strong point in this approach is related to the versatility of the outcomes. In Table 1 it is noticeable that the outcome features of this approach are suitable for presenting the data in a dashboard or scorecard format, since its purpose, users, updates, data and display features are very widespread. This results from the MSM construction simplicity, that is supported by applying a lean tool (VSM) and a lean thinking approach that highlights the value (for any kind of process variable) in a process sequence or system.

Moreover, the target users for the MSM diagrams analysis can be simultaneously the top and middle managers, or even the production line workers, since its mathematical concepts and visual attributes are straightforwardly understandable.

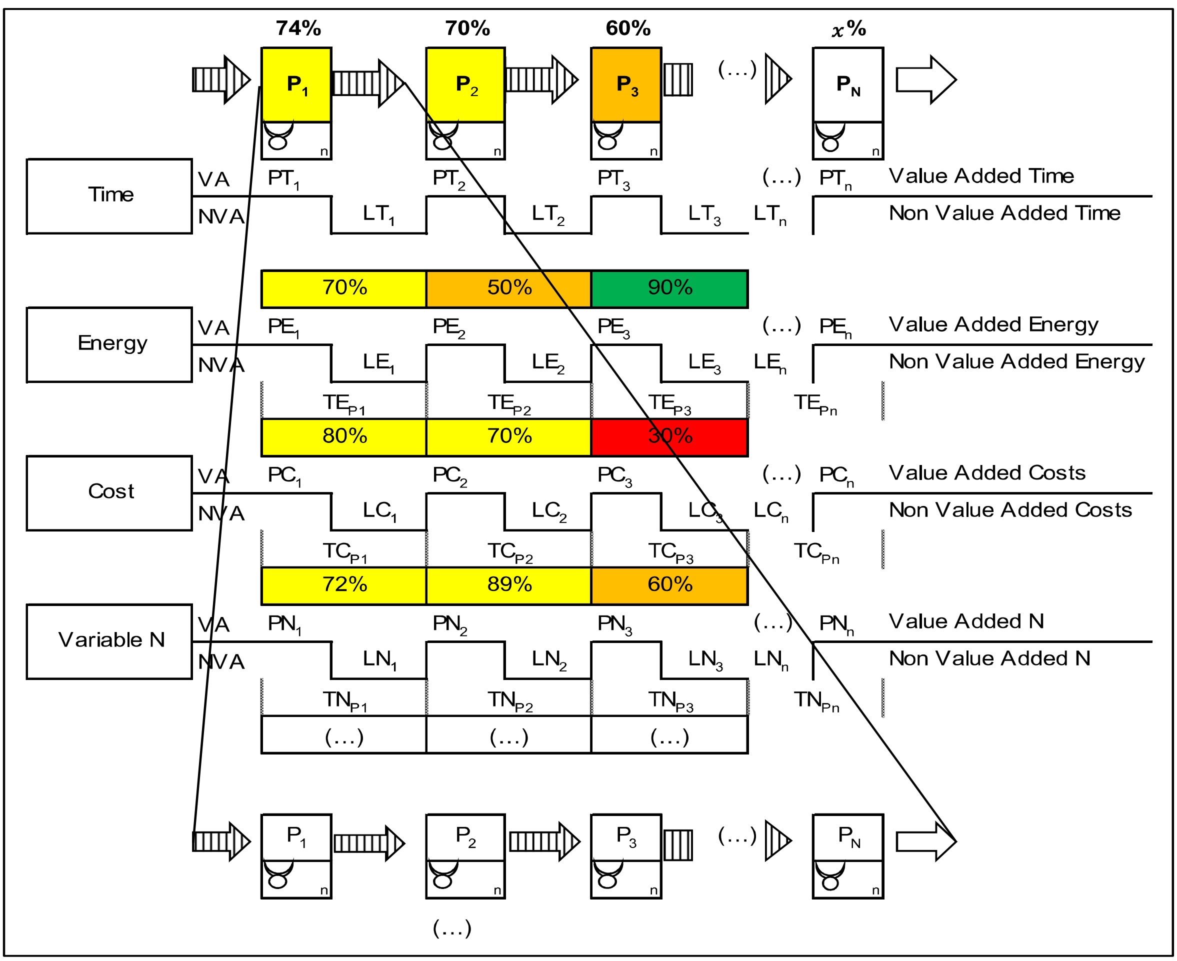

Figure 7: Multi-Layer Stream Mapping Drilldown.

Feature	Dashboard	Scorecard	MSM outcomes
Purpose	Measures performance	Charts progress	Measures performance and Charts progress
Users	Supervisors, specialists	Executives, managers, and staff	Supervisors, specialists, executives, managers, and staff
Updates	Right-time feeds	Periodic snapshots	Periodic snapshots
Data	Events	Summaries	Events and Summaries
Display	Visual graphs, raw data	Visual graphs, comments	Visual graphs, raw data and comments

Table 1: Features of Dashboards and Scorecards [7] compared with Multi-Layer Stream Mapping approach.

5 CONCLUSION

This paper presents a new approach, so called Multi-Layer Stream Mapping (MSM) that brings a new perspective on how eco-efficiency assessments results can be quantified by a discreet method in order that a process sequence or a system can be easily displayed and perceived in a multi-variable diagram. Variables such as energy, raw material consumption and cost can be straightforwardly mapped, as well as composed metrics, such as key environmental performance indicators, financial and production efficiency metrics, or other kind of relevant metrics for the analysis.

Due to the visual management attributes integration and its mathematical simplicity, based on the well-known VSM lean tool, the MSM can be viewed as a promoter for the importance of assessing, evaluating and quantifying environmental aspects of an industrial process or plant, in order to improve global industrial performance. By assessing global performance and considering environmental variables, together with time and cost variables, MSM can improve economic performance. With this approach, many environmental aspects, viewed as costs, can be reduced or eliminated from the process if it is assessed that they don't add value to the product.

Additionally, the demonstrated versatility of the MSM approach, besides giving a whole new dimension to eco-efficiency assessment perception, can be extended and applied with similar good results to the analysis of the performance of other general processes/systems. Other possible applications of the MSM approach can be investigated, such as in project management, logistics, economics, or even in financial systems analysis.

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