Investigating Lean Methodology for Energy Efficient Manufacturing

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Abstract. Due to the growing globalization and the increasing interest in environmental concerns, together with the changing legal and regulations landscape, manufacturers need to change their approach to competition, enhancing their knowledge of the manufacturing systems and of the network of interconnections among physical flows and management and control information flows, while developing systemic methodologies that enable waste reduction of manufacturing resources usage (such as energy). Furthermore, companies are increasingly involved in managing the environment as an opportunity for competitive advantage, which establishes the need to highlight the relationships between environmental impact of their processes and company strategy and objectives. This paper presents a proposal for a lean methodology, called Transformation Distribution and Utilization (namely, T.D.U.) methodology, which allows future factories to identify Value Added energy usage, paving the way to activities that can reduce the related inefficiencies and wastes. The T.D.U. methodology has been tested in real company, MorseTEC Europe, a supplier of systems for European car manufacturers.

Keywords: energy efficiency; sustainable manufacturing; continuous improvement, CIP, lean manufacturing, green manufacturing, energy value stream analysis, EVSA, energy value stream mapping, EVSM.

1 Introduction

Due to the growing globalization and the increasing interest in environmental concerns, together with the changing legal and regulations landscape, manufacturers need to change their approach to competition, enhancing their knowledge of the manufacturing system and of the network of interconnections among physical flows and management and control information flows, while developing systemic methodologies that enable waste reduction of manufacturing resources usage (such as energy). We want to propose a new lean approach, the new Transformation Distribution and Utilization (T.D.U.) methodology with the objective to reduce wasted energy within manufacturing processes and in particular presenting and testing it in a real case study in MorseTEC Europe, a supplier of systems for many European car manufacturers.

adfa, p. 1, 2011.

2 Related Work

The role of energy management in manufacturing is vital and has greatly found application in industry, see for instance [1]. Anyway, there is a wide implementation gap between practice and theory, especially concerning tools for measurement, assessment, control and improvement of energy efficiency in manufacturing companies [2].

Many authors have investigated the aspects concerning the need to enhance manufacturing modeling frameworks and tools to enable energy and resource efficient manufacturing. For instance ISA 95 [3] standard includes process and information flow models enabling representation of additional elements beyond the usual material flows, such as energy consumption, carbon dioxide, emissions, wastes. Various works, such as [4], [5], [6], [7] and [8] extend ISA 95 reasoning by proposing the development of manufacturing modeling frameworks able to capture the complex network of dynamic interactions among the physical flows in the factory, input flows (materials and parts , energy, human resources, etc.) and output flows (products, scrap and solid wastes, emissions, heat, noise etc.), at the different level of the factory, from machine to lines, up to plant/sites.

Other authors have studied modeling concept and methods starting from the observation that machines and other production systems can be in different operating modes (such as "on", "stand by", "processing", etc.) to which correspond different energy consumption profiles. These studies have leveraged on the operating modes concept in many ways, such as supporting manufacturing planning [9], identifying energy saving machine control policies [10], energy monitoring [11]. All these contributions show how energy efficiency can depend on both technical design choices and organizational decisions, such as production planning and control and machine control. Anyway, in literature there is no clear method to extend this approach from the machine/component level to the whole factory.

Furthermore, some authors report that enterprises are increasingly involved in managing the environment as an opportunity for competitive advantage, that requires highlighting the relationships between environmental impact of their processes and company strategy and objectives [12]. Finally we highlight the most interesting related works, which confirm the above mentioned need of energy and resource efficient analysis methods and tools.

Drechsel et al. [13] draw the first steps towards the development of an Energy Value Stream Analysis (EVSA), a new approach extending Value Stream Mapping (VSM), a technique for lean manufacturing, developed to support the identification of productive and non-productive usage of manufacturing resources, for a holistic analysis of energy productivity. The contribution describes how to integrate the EVSA in a Continuous Improvement Process (CIP) in which energy saving potentials are identified by a team involving managers/experts of the various production process steps under analysis. Plehn et al. [14] explore the basic structure of a proposed Environmental Value Stream Mapping (EVSM) as an interface between a multi-criteria performance measurement system and the environmental and economic process flows of a manufacturing system. The main point of the proposed EVSM is the identification of usage of resource flows in different states in time (processing, set-up, stand-by etc.). Fantini et al. [15] propose novel modeling features for each element in the manufacturing systems, features capable to describe their behaviour in terms of resource consumption and release of produced products and parts as well as waste and emissions. The authors propose a systemic approach to manufacturing modeling under a holistic perspective, which includes all elements in a factory such as production systems, technical building services (TBS) and building shell and their network of interconnections with factory management and control levels. To address both manufacturing and environmental

performance, the specification of manufacturing elements requires in fact the description of the whole transformation process enacted by the production systems and the systems supplying them and the dynamics of the material and energy flows in input and of the parts and waste in output.
To summarize, academia and industry experts recognize the widespread need for energy efficiency modeling frameworks and methodologies, able to support collaborative teams in their continuous improvement analysis and programs with the integration of proper KPIs and performance indicators systems.

3 Approach: Lean Methodology for Energy Efficient Manufacturing

3.1 Identification of Value and Non Value Added Energy

It is estimated that in most of the companies, 40-70% of total activities are carried out without adding value to the customer. These activities are considered as waste and competitive advantage can be achieved through these waste reduction [16], [17]. The Lean Production is Toyota Production System approach that that focuses on waste reduction to improve operations' performances, and gave quite interesting results in many implementations (e.g. Womack and Jones [18]; [19]; Lean Enterprise Institute www.lean.org) and therefore it is possible to use this approach also with the aim of identifying the energy wastes and remove them.
One of the most important concepts of the Lean Approach is the distinction between Value Added Activities (VAA) and Non Value Added Activities (NVAA). Especially, VAA are all those activities required for the customers, for which they are willing to pay in achieving the final product. The NVAA activities are those not strictly required such as material handling or inventory holding.
The concept of value added can be applied also in energy management field. According to Frazier [20] the Value Added Energy (V.A.E.)is the energy used for all the activities that create value for costumers, and the Non Value Added Energy (N.V.A.E.), the energy consumption related to the Non Value Added Activities.

$$\text{V.A.E.} = \text{T.E.}$$
$$\text{N.V.A.E} = \text{Actual Energy} - \text{T.E.}$$

where:

- Theoretical energy (T.E.): the minimum energy required to produce the desired transformation;
- Actual Energy: the energy really used for the desired transformation.

Seow and Rahimifard [21] propose a different point of view, in which they identify three energy typologies:

- Theoretical Energy (T.E.): the minimum energy required to carry out the production process.
- Auxiliary Energy (A.E.): the Energy required by the supporting activities and auxiliary equipment for the process. A.E. also includes non-productive modules such as machine tool change, start-up, stand by and cleaning.
- Indirect Energy (I.E.): the energy consumed to ensure the correct workplace conditions for the productive processes such as lighting, heating and ventilation.

Integrating and extending these three different point of views and the aforementioned holistic perspective (11) we propose here as a starting point an high level framework that enables a thorough and systematic assessment of performance of manufacturing systems along multiple dimensions in terms of production performance, economic performance and environ mental impact, suited in particular to identify energy flows, that may happen in production systems and in the services systems (TBS for instance) as well.

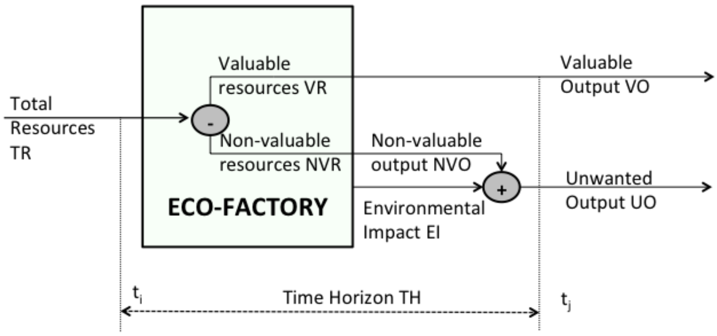

Fig. 1. Valuable, Non Valuable, Un-wanted Flows

Focusing on the physical flows in the system, in Figure 1 we show how Total Resources (TR), such as raw materials, energy, human resources, consumables, etc., can be used:

- partially - the Valuable Resources VR - to produce non-defective final products (valuable output VO);
- partially - namely, the non-valuable resources NVR - can be wasted during non-valuable adding activities or while producing defective products,therefore becoming “NonValuable” Output NVO. These w asted resources can be considered “Unwanted” Output (UO), toge ther with all environmental impacts (EI).

The main idea of this paper is finding valuable and non-valuable usage of resources along their whole physical flows, in particular concerning how to identify Value Added Energy, instead that along the traditional transformation flow, for instance from raw materials to product/part produced. Based on the aforementioned three different point of views proposed by literature, Theoretical Energy is the proxy for the Value Added Energy, but under the holistic perspective we can see that this is not enough, as it does not include all energy flows that allow a quality compliant production. We want to introduce in this paper a new concept of VAE, considering the concept of value related to what the customer is willing to pay for the final product compliant with the desired quality level.
Therefore we propose to classify energy into three different typologies:

- Direct Energy (D.E.): VAE for the final clients, that is the theoretical energy used for all the activities that create value for costumers.
- Accessory Energy (A.E): VAE for the internal client, that is the theoretical energy used to allow the factory operators to perform their work in comfortable conditions, (for instance, comfort temperature and lighting level).
- Actual Energy: the energy actually used for the desired transformation.

Based on this classification we can compute the VAE is:

Value Added Energy = Direct Energy (DE) + Accessory Energy (A.E.)

The difference between Actual Energy and VAE is waste and can be considered a potential opportunity for improvement. The table below (Table 1) presents some improvement areas for energy efficiency, by translating the 7 wastes, considered in Lean Philosophy, in energy wastes.

7 Wastes	Energy Wasted connected with production
Transport	Energy used for transport inside / out the warehouse, plant and factory
Inventory	Heating, cooling and lighting inventory storage and warehouse
Motion	Heating, cooling and lighting inventory storage and warehouse
Waiting	Heating, cooling, and lighting during production downtime
Overproduction	Energy consumed in operating equipment to make un-necessary products
Over-processing	Energy to unnecessary processing
Defects	Energy used to process defective products

Table 1. Energy Wastes and Improvement Areas

3.2 T.D.U. Methodology

The Transformation, Distribution and Utilization (T.D.U.) methodology we propose is based on identification of Value Added Energy flows in three phases:

- *Transformation phase*: the energy sources are transformed, if needed, in the energy used directly in the production processes.
- *Distribution phase:* the energy and related transformed vectors (such as compressed air) are brought where the transformation takes place.
- *Utilization phase:* the energy is finally consumed on the shop floor in the production processes (compressed air and thermal energy; electrical driving force and fuel etc.) and on the work place (lighting and heating ventilation and air conditioning systems).

This methodology is simple enough to be used in SMEs, as it is based on a checklist approach that drives the user in identifying which kinds of utilities (production systems, TBS etc.) are involved, in particular focusing on each different phase.
Once defined all the utilities involved in each phase, for each of them a checklist is provided, that encloses all the energy saving activities that can be implemented in that specific utility.
This checklist was obtained by the analysis of scientific publications, documentations prepared by the E.N.E.A. (Italian national agency of new technologies, energy efficiency and sustainable development), reports published by the U.S. Environmental Protection Agency, real case studies of success ful applications of energy efficiency activities and direct evidence of meetings and conferences. In this way users of the T.D.U. methodology have in few pages the summary of the state of art of the industrial energy efficiency and can identify in a few minutes which activities can be implemented for improving the energy efficiency of their processes.
The energy flow is designed as follow:

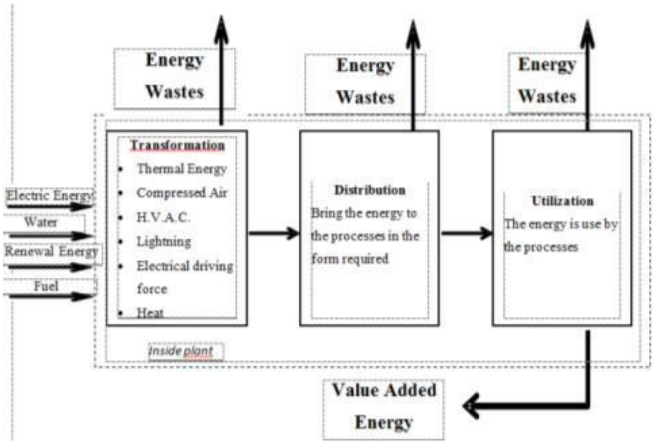

Fig. 2. Energy flow within the 3 main phases.

This methodology has been applied and tested with a great success in MorseTEC Europe, the European division of BorgWarner Group.

Application Case Study

MorseTEC Europe has represented for over 15 years the expression of the European division of BorgWarner Group. Located in Arcore, 20 km northeast of Milan, MorseTEC Europe is a partner of absolute importance as a supplier of systems for most European car manufacturers (Ford, Audi, General Motors, Fiat, Volkswagen, Jaguar and PSA) by offering exclusive service, competence and experience in the development and production of distribution systems and transmission chain.
In this section there will be presented some activities implemented in the plant of Arcore of the BorgWarner MorseTEC Europe after the application of the T.D.U. methodology.
Specifically are reported two examples of the activities implemented in the Morse- TEC plant: heat recovery from compressors and energy consumption reduction by equipping compressor with an inverter.

Energy Saving Activity #1: heat recovery from compressors

- T.D.U. Phase: Transformation_compressed air
- Checklist question: Is the heat emitted by your compressors recovered?
- Answer: No
- Solution: Purchase of Heat exchanger for compressors
- Type of activity: Opportunity
- Status: Completed

This activity consists in recovering the heat generated during the compression of the air. This energy saving solution is a relatively simple and in recent years has been implemented in different production realities. MorseTEC has three big compressors and decided to implement this solution on its 135 kW compressor. With this energy available and an opportune heat exchanger installed in this machine it is possible to heat enough water for HVAC system for heating 1000 m^2. MorseTEC now uses the recovered power for heating his administrative offices, with have a total surface area of 900 m^2 and an average height of 2.8 m. The excess power is used to produce hot water for showers of the workers restrooms.

For implementing this solution it has been made a feasibility study for understanding the potentiality of this activity and have spent about 40.000 € for the heat recovery equipment made off by an heat exchanger, insulate piping necessary to bring the hot water to the H.V.A.C. system and 2 insulated tanks for storing the hot water.

Most part of this investment has been financed by other energy saving activities: it has been calculated that the economic saving generated by this solution amounts to 18.000 €/year. MorseTEC buys externally the heating water service and this saving represents the thermal energy consumption that the company is able to recover from its compressor . The expected payback time of this investment is equal to 2 years and 3 months.

Energy Saving Activity # 6: Compressor Equipped with an Inverter

- T.D.U. phase: Transformation_compressed air
- Check list question: Is your compressor equipped with an inverter?
- Answer: No
- Solution: Purchase of a compressor with an Inverter
- Type of activity: Opportunity
- Identified NVA energy: 98.500 kWh / year
- Status : Completed

4 Conclusions

As we stated before, putting effort in improving energy efficiency process is be- coming more and more relevant for Companies, to reach a higher competition level. Lean Approach concept of waste management is not only related to products and time, but also can be translated to energy. The approach proposed for improving energy efficiency in manufacturing takes into account many contributions from literature, however its innovation is on how to identify Value Added Energy, based on the classification of energy in three different categories. Then we proposed a methodology, called T.D.U. methodology with the main objective to identify three main different phases in which applying a checklist for each facility used in every phase. The checklist is formed by several standard questions, and answering to that questions leads to implement specific activities for removing part of NVAE. MorseTec Europe (European level manufacturer system provider) applied the T.D.U. methodology and we briefly reported the results of the activities done: in the table below costs and benefits obtained by the two activities are summarized :

Activity	T.D.U. Phase	Yearly Saving €/y	Status
Heat Recover from Compressor	T	18.000	100%
Compressor with Inverter	T	13.500	100%

Table 1 MorseTEC case study: cost benefit analysis

By applying this easy methodology is possible to reach high economic and environmental results. The next step of this work is to better and deeper relate economical performances to environmental ones.

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