Development of sustainable manufacturing indicators focusing on human work and environment

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Abstract: Over the last few years, sustainability has become a major challenge for manufacturing systems, due to the rising awareness of the impact of their activities on the environment, society and economy. In order to measure the sustainability of a product, process or company, metrics for sustainable manufacturing were developed and proposed in the scientific literature. This paper proposes a set of indicators for sustainable manufacturing evaluation focusing on human work and environment. More in detail, human work-related indicators arise from Maslow's hierarchy of needs, while environmental indices derive from an industrial case. Results provide a basis for decision-making, and are expected to be incorporated into the companies' sustainable strategies.

Key-Words: Sustainable manufacturing, Maslow, indicators, human work, environment, production.

1. Introduction

Up until a few decades ago, companies' success was mainly measured on their financial performances ignoring further effects of their activities. The responsibility of business in a free-enterprise system was, with very few exceptions [1], to increase its profits following the statement of one of the main economist of the last century, Milton Friedman [2]. In the last few years the population growth, the scarcity of natural resources, the raising energy costs, the high pollution level recorded in the most developed and in the developing Countries, with China and United States in forefront [3], the increasing regulations in respect of environmental issues and the increased pressure exerted by customers on companies to create products in a sustainable manner [4, 5], forced industries to turn on a dime developing and implementing tools which meet the sustainable manufacturing fundamentals, and which balance three principal requirements related to environmental, economic, and social objectives (Figure 1) [6].

1.2 Sustainable Manufacturing definitions

There are several definitions of *sustainability*, but the most known is the one coined by the United Nations [7] in 1987 which defined Sustainable Development as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". According to the definition presented by the U.S. Dept. of Commerce, sustainable manufacturing involves "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound" [8].

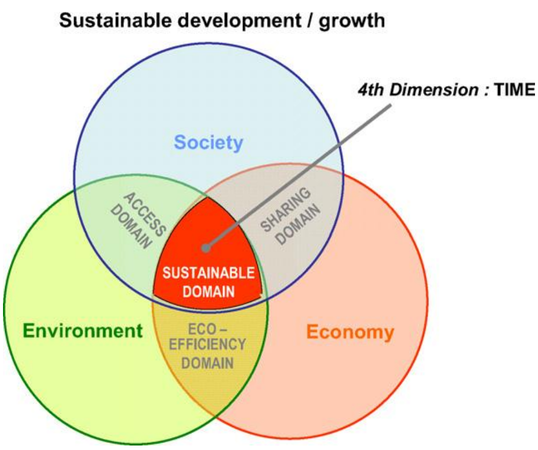

Fig. 1. Triple Bottom Line [6].

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A more technical definition is given by Rachuri et al. which define Sustainable Manufacturing as a system approach for the creation and distribution (supply chain) of innovative products and services that: “minimizes resources (inputs such as materials, energy, water, and land); eliminates toxic substances; and produces zero waste that in effect reduces greenhouse gases, e.g., carbon intensity, across the entire life cycle of products and services” [9]. Here Sustainable Manufacturing is defined as the essence of business, whose main purpose should be the creation of wealth throughout its whole system.

Thus, Sustainable Manufacturing is oriented towards the community rather than individuals. Sustainability has become the new manufacturing paradigm and manufacturers have been developing several sustainable solutions. However, a lack in effective sustainability measurements can be observed. In this context, the present research work describes the main indicators set that can be consulted in literature (Section 2), provides an infrastructure for measuring the sustainability performance in manufacturing processes focusing on environmental and employee-related social indicators (Section 3), and describes an example for measuring the environmental impact of a specific manufacturing process (Section 4). The last section (Section 5) includes conclusions and future research directions.

2. Literature review

Companies and research organizations developed several sustainability metrics including qualitative and quantitative indicators. The methodologies proposed tried to measure sustainability including social, economic and environmental aspects. These aspects are interrelated in a complex way making the building up of such metrics a complicated issue. For instance, a high-rate usage of sustainable materials may result in unsustainable costs, optimizing the environment, but raising financial issues. The result is that most of the tools are not specific, vague and poorly defined. However, among the dozens of methods developed, some methods that are considered more detailed and more effective than the others can be found in literature.

Life Cycle Assessment is regarded as one of the most accurate tool to quantify the sustainability of a certain process or product. LCA is an holistic view of the environmental effects instead of point-based monitoring of individual aspects, considering the entire life cycle “from cradle to grave”. LCA is applied in a variety of applications including food and beverage industry, automotive applications, building assessments, bioenergy systems [10-13].

LCA is a complete and detailed method which gives accurate results. On the other hand, it is very difficult to carry out because of the large amount of data required, and because of the complexity in identifying the boundaries. The OECD sustainable manufacturing toolkit provides a practical starting point for measuring the sustainability at the facility level identifying and quantifying inputs, operations and process impact in order to improve the environmental efficiency, and so contributing to the green growth and sustainable development. The toolkit identifies eighteen indicators and gives advices on the steps to be undertaken in order to measure the environmental performance [14]. These indicators can be useful in decision-making and can be used for all types of manufacturing systems. In 2007, Ford introduced a Product Sustainability Index (PSI), in order to measure the sustainability of the produced cars. The index includes 8 indicators and it is based on the Life Cycle Assessment, Life Cycle Cost, external certified aspects and other relevant issues such as safety, material usage and noise emissions [15]. Probably, PSI index represents to date the most complete methodology for measuring the sustainability in the automotive sector. Veleva and Ellebecker suggested a new methodology of core and supplemental indicators to support companies in measuring the sustainability of their activities. Most of the twenty-two proposed indicators apply to product, process and facility levels and include social, economic and environmental aspects [16].

University of Kentucky developed a product sustainability index (ProdSI) based on a five level hierarchical framework [17]. The ProdSI is divided into three sub-indexes: environment, economy and society, each of which itself contains groups. Then sub-groups are defined, and each of them contains the individual metrics. The evaluation process consists of a series of operational procedures, starting with individual metrics measurement. Once the data are collected, they need to be normalized due to their heterogeneous nature. The individual metrics are usually normalized to a single scale from 0 to 10, where 0 represents the worst case and 10 the best case. The following step is the assignment of weights. Weighting is a very sensitive process since it affects the accuracy of the measurement, so the choice of the weights is a crucial step. Equal weighting may represent a suitable method, but the fact that it may not truly reflect the importance of the elements may bring to the choice of other methods, such as questionnaires and surveys to be

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filled out by experts. Once the weighted process is completed, the ProdSI can be calculated as:

$$ProdSI = \frac{1}{3}\,[Ec + Ev + Sc]$$

where *Ec* is the score attributed to the economy impact sub-index, *Ev* the score attributed to the environment impact sub-index and *Sc* is the score attributed to the social impact sub-index.

In order to address the sustainability challenge, the National Institute of Standards and Technology (NIST) developed a categorization of sustainability indicators that classifies a large number of indicators into appropriate categories and sub-categories [18]. NIST Sustainable Manufacturing Repository includes 212 indicators organized in 5 categories [19]:

- Environmental stewardship (77 indicators);
- Economic growth (23 indicators);
- Social well-being dimension (70 indicators);
- Performance management (30 indicators);
- Technology (12 indicators).

3. Human work-related indicators

Social aspects have become a major focus in the context of sustainability [20]. For instance, Life Cycle Assessment, on principle including only environmental aspects, supplements these aspects with social and sociological indicators, creating a new method known as Social Life Cycle Assessment (SLCA). Social sustainability includes three groups: employees, customers and community. In this paper the focus is on workers. The Human work-related indicators developed arise from Maslow's, Herzberg's and McGregor's theories [21-23]. In 1943, Abraham Maslow published "A Theory of Human Motivation", describing his hierarchy of needs, a motivational theory valid for understanding human motivation, management training and personal development. Maslow's theory can be seen in the work environment as the responsibility of employers to provide a workplace that encourages and enables employees to reach the self-actualization. Maslow's hierarchy of needs sets out five fundamental needs and their hierarchical nature. First, at the bottom, we have the physiological needs. Then, there is the desire to be safe and secure. At the third level comes the need for love, friendship and belonging. The next stage is the esteem, while the top is labeled with the term self-actualization. The first two steps are included in the hygiene factors theorized by Herzberg and in the theory X by McGregor. The next three stages represent motivators on Herzberg's theory and theory Y in McGregor's research (Figure 2). The work environment has an important role in shaping the individual, as people spend an important part of the day within the working environment. Thus, it essential that employees work in safe environment that fulfills their expectations. In the next sub-sections indicators for each stage of Maslow's hierarchy are identified.

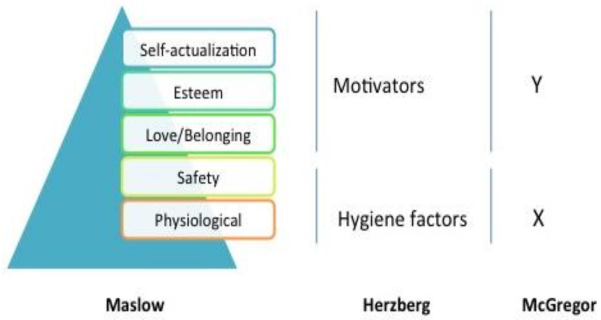

Fig. 2. Major motivational theories [21-23].

3.1 Physiological needs

One limitation of the modern industry is its dependence on low cost workers [24]. Employers should ensure a salary level which must be at least at the same level of the minimum salary. Salary Level (SL) indicator arises from this statement and can be formulated as follows:

$$SL = \frac{lowest\ salary}{minimum\ salary\ by\ law} \geq 1$$

The string of workers' suicides has gained significant attention in East Countries [25-27]. These tragedies can be attributed to the overwork which resulted in the death of employees. Number of Hours Worked Rate (NHW) and Employee Deceases Due To the Work Environment (ED) indicators refer to that situation:

$$NHW = \frac{No.of\ hrs\ worked\ x\ week}{168\ (hours\ in\ 1\ week)} \leq 25\%$$

$$ED = \frac{No.of\ deceases}{Total\ no.of\ employees} = 0$$

Child labor is defined in ILO Conventions [28]. It is the type of work that children should not be doing because they are too young to work or, even they are old enough to work, if the working environment is dangerous or unsuitable for them. Child Labour (CL) indicator can be formulated as follows:

$$CL = \frac{No. of\ children}{Total\ no. of\ employees} = 0$$

In order to be sustainable, companies should record a Salary Level with a minimum value of 1, a Number of Hours Worked Rate with a value of less than 25%, an Employee Decease and Child Labour value of 0.

3.2 Safe and security needs

Workplace safety refers to how working conditions affect health and well-being. Occupational risk prevention and control requires the implementation of health and safety practices [29]. Injuries and Illnesses Rate (IIR) can be applied to quantify the safety level of a company [30]:

$$IIR = \frac{Total\ injures\ and\ illnesses * 200000}{No. of\ hours\ worked\ by\ all\ employees}$$

Where the value 200,000 used in this calculation is the equivalent number of work-hours for 100 employees working 40 hours per week for 50 weeks. Job security refers to the probability that the employee will keep his/her job. Permanent contracts assures a higher contractual security perception. Contract Type Indicator (CT) reflects the percentage of employees with a permanent contract:

$$CT = \frac{No. of\ permanent\ contract}{Total\ No. of\ contracts}$$

Higher the rate is, higher the company's efforts in assuring security to the workers are.

3.3 Belonging needs

Employee engagement can be defined as the high level of employee involvement, commitment to the organization and job satisfaction. Employee engagement brings several benefits to the organization since the employees are more willing to share information, accept challenging tasks and projects, cooperate and remain for a longer period in the company [31, 32]. Consequently, the organization performance will be positively affected by employees engagement programs [33, 34]. Employee engagement can be measured considering the turnover rate. Higher the rate is, less the employees are engaged with the company. Turnover Rate (TR) can be calculated as follows:

$$TR = \frac{No. of\ separations\ during\ the\ year}{avg\ no.\ of\ employees\ during\ the\ year}$$

3.4 Esteem

Employees generally want to be more than just a member of the team. In order to satisfy the esteem needs, companies should provide a motivating workplace. In order to evaluate the level of satisfaction, questionnaires and surveys may be used in order to build up the Job Satisfaction (JS) indicator:

$$JS = \frac{No. of\ satisfied\ people}{No. of\ people\ of\ the\ company}$$

Training the workforce and keep the employees up-do-date with new tools and new technologies is essential for being competitive in the industry environment. In order to measure companies' training programs (TH) the following indicator is proposed:

$$TH = \frac{No. of\ training\ hrs}{Total\ no. of\ hrs\ worked}$$

The pay gap between CEOs and employees may demotivate lower paid workers. Peter Drucker, one of the most celebrated management theorist, considered 25-to-1 the appropriate limit. In his opinion, excessively high multiples undermine teamwork and promote a winner-takes-all mentality which is dangerous for business [35]. The Compensation Gap (CG) indicator comes from his view and has been formulated as follows:

$$CG = \frac{Top\ salary}{Lowest\ salary} \leq 25$$

Once the four stages are completed employees can reach the self-actualization becoming critical resources in the business environment.

4. Environmental indicators

Beside the above mentioned indicators, environmental indices have to be considered as well. In this context, manufacturing processes represent a single, essential piece in the sustainability puzzle, as shown in Figure 1.

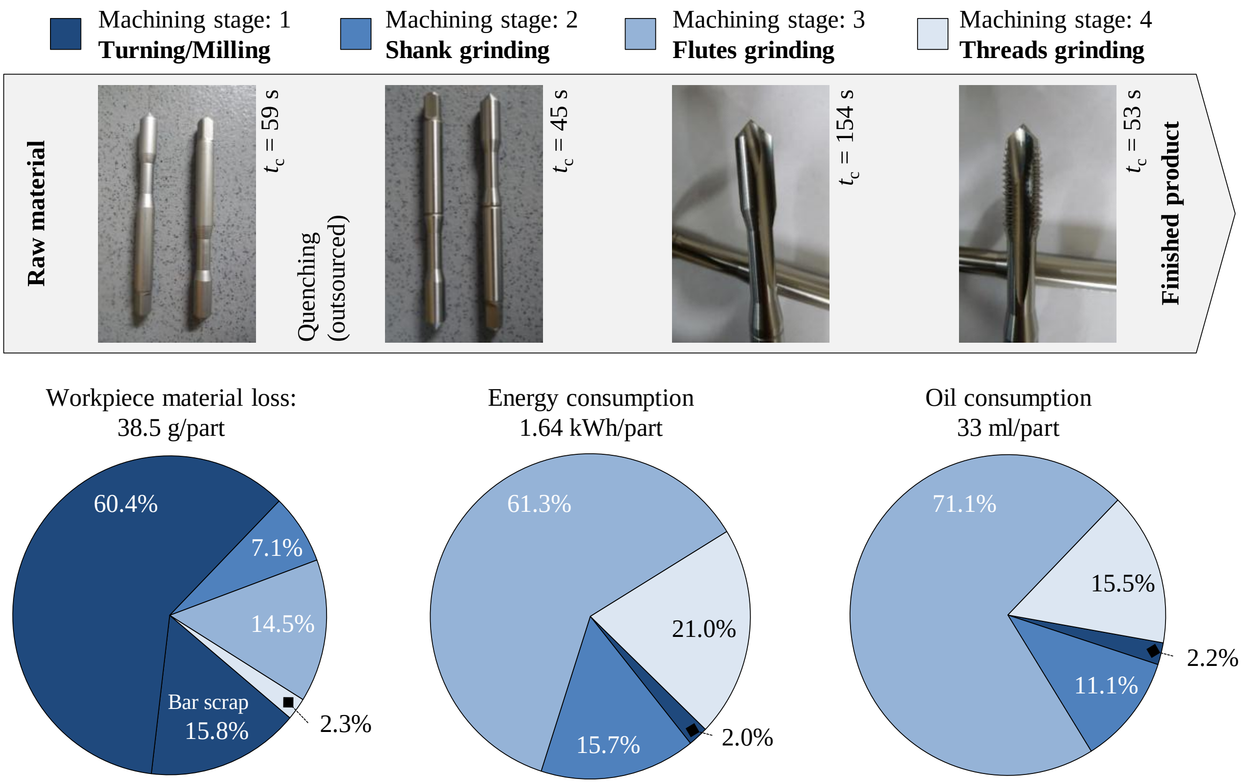

Fig. 3. A structured analytical approach for tap manufacturing: main results [36].

The optimization of production and process management, facing with the balance between technological requirements and environmental impact, is still an open challenge. In order to provide decision-making basis for the business strategy development, detailed and broad-spectrum analyses of different production processes have to be industrially performed.

An example, reporting the application of an analytical approach to a tool manufacturing process, was recently published by the authors [36]. The production of a tap, considering all the steps from the raw material up to the finished product, was investigated. For each stage (namely *(i)* turning/ milling, *(ii)* shank grinding, *(iii)* flutes grinding, and *(iv)* threads grinding) all the resources consumed during the machining operations (including electrical energy, lubricants, cutting tools, and material scraps) were measured and associated to each produced unit, according to the following equations:

$$Energy\ Consumption_{1\,tap}^{i-th\,stage} = \frac{Total\ energy\ consumption^{j-th\,machine\,tool}}{Number\ of\ taps\ machined^{j-th\,machine\,tool}}$$

$$Oil\ Consumption_{1\,tap}^{i-th\,stage} = \frac{Total\ oil\ consumption_{1\,year}^{j-th\,machine\,tool}}{Number\ of\ taps\ machined_{1\,year}^{j-th\,machine\,tool}}$$

$$Tool\ Consumption_{1\,tap}^{k-th\,cutting\,tool} = \frac{1^{k-th\,cutting\,tool}}{Number\ of\ taps\ machined^{\,k-th\,cutting\,tool}}$$

$$Workpiece\ material\ loss_{1\,tap}^{i-th\,stage} = \frac{Workpiece\ material\ loss^{j-th\,machine\,tool}}{Number\ of\ taps\ machined^{j-th\,machine\,tool}}$$

All the details are discussed in [36], and Figure 3 resumes the main results. The data needed for the life cycle inventory were not difficult to collect. Starting from the analysis of such indicators, strategies for optimization were proposed.

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5. Conclusions and outlooks

The manufacturing firms are under pressure to measure and quantify the sustainability of their activities. The identification of critical sustainable manufacturing indicators represents an effective method to address this challenge. In this paper, human work-related indicators were identified on the basis of the main motivational theories. Such indicators have to be coupled with environmental impact analysis, in order to be incorporate into the business strategies and to be used as the basis for decision-making concerning sustainability issues. These indicators can be easily developed, used and implemented at a company level, as the required data are mostly known by the production and human resource departments. Future research shall focus on the identification of additional indicators and on the construction of ad-hoc questionnaires for weighting indicators, in order to develop a complete framework for the evaluation of the companies' sustainability with the aim of classifying firms considering their sustainability engagement.

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