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IFAC-PapersOnLine 49-32 (2016) 135–140

An Emerging Industrial Business Model considering Sustainability Evaluation and using Cyber Physical System Technology and Modelling Techniques

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Abstract: There is a kind of movement for people to consider sustainability in all their daily activities, not only in the acquisition of goods and services but including the care for health. This induces the emergence of a new business model. Any type of production system (PS) should thus consider sustainability in all its activities and a relationship, which includes not only customers but suppliers, and partners involved from conception, design, manufacturing and provide even service after the use and the disposal of the products. Therefore, an evaluation procedure for PS is proposed to monitor four aspects of sustainability, namely: environmental, social, economical and technological. A framework is considered to deal with the concepts of sustainability and to evaluate performance in industrial PSs considering the indicators to qualify and to quantify their sustainability. It adopts the Petri net technique and extensions of the ANSI/ISA95; Cyber Physical System (CPS) and Smart Grid resources are also considered to treat information processing, storage and access flows by each system component and a Cloud Computing System to connect dispersed PSs. In addition, an evaluation process is systematized to support sustainable PSs by the rational use of production resources and the environment, to guarantee the safety of employees and to maintain the economic profitability of the company, thus, making production processes more efficient.

Keywords: sustainable manufacturing, performance evaluation, business model, cyber physical system, Petri net.

1. INTRODUCTION

People are concerned about considering sustainability in their daily activities. Production system (PS) as a whole should consider sustainability in all their activities and a relationship, which includes not only customers but suppliers, and partners involved from conception, design, manufacturing and providing even service after the use and the disposal of the products. The need to include sustainability in the PS conception was brought up by entities such as the United Nations (UN) and the World Commission on Environment and Development (WCED, 1987), and events such as Rio 92, Kyoto 97 and, more recently, Doha 2015. Currently, the PS performance must be concerned not only with productivity aspects but also with sustainability indicators, such as reduction of negative impacts on energy conservation and natural resources, safety assurance of employees' communities and consumers, viability and profitability of business and best policies for using of equipment and tools. This induces the emergence of a new business model. However, industrial norms and standards such as ANSI/ISA95 do not explicitly consider how to treat sustainability indicators in PS design and its control system (ANSI/ISA, 2005). Therefore, this paper proposes a framework to systemize the PS sustainability performance evaluation using sustainability indexes. The framework adopts the Petri net technique and extensions of the ANSI/ISA95 norms; it also considers simulation as an analysis correlation data tool (e.g., Life Cycle Impact Assessment (LCiA) is based on "indicators", in which the effects of resource use and emissions generated are grouped and quantified in a limited number of impact categories that may be of weighted importance (Otero, 2011)) and decision-making method (e.g. Multiple Criteria Decision Analysis (MCDA) chooses the best alternative from a range of alternatives in an environment of conflicting and competing criteria (Otero, 2011)), and a sustainable PS register based on green product seal. To define the elements of the framework and its functionalities, a modelling approach is adopted to ensure a formal way to verify and to validate the dynamic behavior of the system. The evaluation processes treat information processing, storage and access flows by each system component considering the Cyber Physical System (CPS), Smart Grid resources and a Cloud Computing System to connect dispersed PSs. To evaluate the sustainability of PSs, a set of indicators must be computed to quantify and to qualify the PS performance related to them. The indicators are based on information from a smart data acquisition

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Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.12.203

system that reads environment signals using sensors connected to the production machinery. These indicators must be used to monitor, to guarantee or to improve certain grade of sustainability for PS, ensuring a positive impact on the environment, employees' satisfaction, proper use of technology and profitable manufactured products. Thereby, the framework also supports product classification based on the sustainability seal. This proposal is based on the scope that innovative solutions to improve process or physical structures in PSs are achieved by exploring new technologies and different approaches, but based on substantiated theories and techniques. Usually, a PS is seen only as a system that processes materials for manufacturing physical products; yet it should now be treated as a service-oriented system so that service-oriented business practices are applied to optimize production processes to meet customer demand considering product features, deadline, costs, security, reliability, logistics, resource-efficient production, and sustainability.

The text is structured as follows: section 2 presents a review of manufacturing systems and sustainability indicators. Section 3 shows the framework considered for the systematization of the performance evaluation process and presents the green seal to register sustainability in PSs. Section 4 describes an example case of use of the simulation and analysis procedure. Section 5 produces the conclusions and proposes further works.

2. MANUFACTURING SYSTEMS AND SUSTAINABILITY METRICS

2.1 Sustainable Manufacturing System

Esmaeilian *et al.* (2016) describe manufacturing conceptually as an industrial productive process in which raw materials are transformed into finished products which will be placed in the market. These processes are in constant innovation due to the development of technology, new tools and manufacturing methods. A sustainable manufacturing system is a product-oriented system and ensures positive aspects related with economical, social, environmental and technological points of view, which is usually considered three dimensions (economical, environmental and social) called Triple Bottom Line (TBL) by Elkington (1997). This approach can be extended to PS so that sustainable PSs take into account all the production stages and associated services, besides the product life cycle, from the acquisition of resources to the end of the production process and recycling the product in its obsolescence. (Otero *et al.*, 2011)

The main objective of sustainable PSs is not to unbalance the environment, but to maintain the quality of life for present generations without causing irreparable damage to the ecosystem for future generations. By the wise use of economical, social, environmental and technological aspects, it wants to achieve a balance. Thus, it keeps the economic profitability of the company by the production process efficiency. In this context, Zhang *et al.* (2013), Jayal *et al.* (2010) describe the 6R methodologies: reduce, remanufacture, reuse, recover, recycle and redesign.

2.2 Indicators of sustainability

Sustainability indicators have three main objectives: raising awareness and understanding, informing decision-making, and measuring progress toward established goals (Veleva *et al.*, 2001). O'Brien (1999) says that indicators are qualitative or quantitative values used to evaluate the sustainability aspects of a system. According to Amrina and Yusof (2011), there are different approaches to be considered besides measuring a set of indicators, such as defining the actions set, in which the indicators must be verified. The objective of the measurement is to identify a specific area to apply improvements related to sustainability in PS activities. (Joung *et al.*, 2013). A fundamental stage is the analysis and interpretation of the data achieved, when the difficulties lie in the complexity related to the number of indicators selected (OECD, 2001; OECD, 2011).

Table 1 shows a reduced list of four sustainability aspects indicators, in which the indexes of each indicator should be calculated based on the demand of the production data.

Table 1 - Sustainability aspects and indicators

Item	Economical indicators
1	Material Cost
2	Energy Cost
3	Labour Cost
4	Production Investment Cost
5	Trainingt Cost

Item	Social indicators
1	Work Days Lost
2	Labor Productivity
3	Employee Trained in Sustainability
4	Customer Complaints
5	Publication of Sustainability Report

Item	Environmental indicators
1	Greenhouse Gas Emissions
2	Materials Reused / Recycled used in Products
3	Waste materials Discarded
4	Total Energy Consumed
5	Water Reuse

Item	Technological indicators
1	Protective Equipment and Personal Safety
2	Innovation and Investment in R&D
3	Updated Software and Hardware
4	Service Providers with Environmental Certification
5	Maintenance Program Policy

The degree of sustainability may be also used as a metric to evaluate the performance of PS (Joung *et al.,* 2013). According to ISO (2010) and ISO (2014), the performance measure is treated as part of an industrial process creation value.

3. FRAMEWORK