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A Framework to Evaluate the Performance of a New Industrial Business Model

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Abstract: In a new industrial business model, all aspects of sustainability, i.e. (i) environmental for reduction of negative impacts of using resources, (ii) economic for viability and profitability of business, (iii) social for assuring the safety of employees, communities and consumers, and (iv) technological for efficient and safe use of production resources, need to be effectively incorporated in the productive activities. On the other hand, existing decision-making structures in industries do not explicitly consider how to deal with sustainability indicators when developing a productive system (PS) and its control system. Therefore, this paper discusses the components of a framework and their interactions to apply new concepts to evaluate performance in industrial PSs considering the indicators to qualify and to quantify their sustainability. The framework adopts the Petri net technique and extensions of the ANSI/ISA 95 standard to systemize the evaluation process. This approach assures a formal way to verify and to validate the system sustainability. Besides, the framework considers information processing, storage and access flows between each system component under Cyber Physical System (CPS) and Cloud Computing concepts.

Keywords: Sustainable manufacturing, performance evaluation, cyber physical system, business model

1. INTRODUCTION

In accordance with researchers such as Jayal *et al.* (2010), a new industrial business model needs to consider sustainability as the guide of productive activities and improvement in trade relationship, employment relationship, and involvement with the local community, environmental policy, and technology innovation. From the point-of-view of technological innovation, a productive system (PS) was designed to include (Goldstone, 2002; Bagheri *et al.*, 2015) concepts such as standardization, customization and reconfiguration capabilities. However, the focus on productivity and the problem of increasing waste of natural resources still remain. Since the mid-80s, due to the increasing shortage of raw materials, non-governmental organizations, such as the Roman Club, have warned about the need to include sustainability in the PS conception (Goldstone, 2002; Senge *et al.,* 2001; and McDonough and Braungart, 1998). Thereby initiatives by the United Nations (UN), such as the World Commission on Environment and Development (WCED, 1987), and events such as Rio 92, Kyoto 97 and more recently Doha 2015 emerged. It is currently clear that PS performance must be concerned not only with productivity parameters but also with sustainability aspects, such as the reduction of negative impacts, energy conservation and use of natural resources, management practices for assuring the safety of employees, communities and consumers, best practices of business feasibility and profitability, and efficient and safe usage of production resources.

In this context, we note that existing industrial 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 introduces a framework to evaluate the PS sustainability performance based on sustainability indexes. The framework is defined by a set of concepts; methods and tools organized in a rational structure to solve a real need, that is, to make the process of sustainability performance evaluation feasible in a PS. The framework adopts Petri net (PN) (Silva, 2013)based techniques for process modelling, a review of the ANSI/ISA95 standard in order to include sustainability indicators, Cyber-physical System (CPS) and cloud computing concepts to exchange data among system elements. The performance and sustainability evaluation is based on computational infrastructure with a smart data acquisition system to read environment signals of sensors in production machinery (Bagheri *et al.*, 2015). CPS and cloud computing infrastructure assures that data processing, storing and accessing occur whatever the geographical location. A set of indicators are then measured to quantify and to qualify the PS performance, and to guarantee a certain degree of sustainability of the PS, positive impact on the environment, employees' satisfaction, proper use of technology and profitable manufactured products, thus balancing all the aspects of sustainability.

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The proposed framework considers the scope that innovative solutions to improve PS processes are achieved by exploring new technologies and different approaches but based on sound theories and techniques. Usually, a PS is seen only as a system that processes materials for manufacturing physical products but it is here treated as a service-oriented system so that service-oriented business practices are applied to optimize productive processes to meet customer demand considering product features, deadline, costs, security, reliability, logistic and sustainability, and resource-efficient production.

The text is structured in sections: section 2 provides the background for the work. Section 3 discusses the framework proposed to evaluate a PS performance process. Section 4 describes an example of data processing using the framework. Section 5 reports the conclusions and suggests further works.

2. SUSTAINABLE MANUFACTURING AND INDUSTRIAL STANDARDS

2.1 Sustainable Manufactuirng

Esmaeilian *et al.* (2016) describes manufacturing as an industrial productive process in which raw materials are converted into finished products which will be placed in the market. These processes undergo constant innovation by the development of technology, creation of new tools and manufacturing methods. A sustainable production system is a product-oriented system which usually considers three dimensions (economic, environmental and social) called Triple Bottom Line (TBL) by Elkington (1997). It takes into account all stages of production and the product life cycle, from the acquisition of resources to the end of the production process, and recycling of the product in its obsolescence.

A challenge in sustainable manufacturing systems is keeping the economic profitability of the company balanced with the maintenance of the quality of life for present generations without causing irreparable damage to the ecosystem of the future generations; by consciously using economic, social, environmental and technological aspects, this balance is achieved. Zhang *et al.* (2013) and Jayal *et al*. (2010) describe the 6R methodology for this: reduce, re-manufacturing, reuse, recover, recycle and redesign.

We here consider 4Rs (reduce, reuse, recycle and recover), considering that most of the manufacturing industries could not currently meet yet all the6Rs.

2.2 Sustainability Indicators

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) describes indicators as 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 instead of only measuring a set of indicators, but also the definition of the actions set, in which the indicators must be verified. The measurement aims at identifying a specific area to apply improvements related to sustainability in PS activities (Joung *et al*., 2013). A fundamental stage is analyzing and interpreting the data, in which the difficulties lie in the complexity related to quantifying the indicators selected (OECD, 2001; OECD, 2011).

According to ISO (2010) and ISO (2014), the performance measure is treated as part of an industrial process creation value, and in the context of a new industrial business model mentioned previously, the degree of sustainability must be included into the metric to evaluate the PS performance (Joung *et al.,* 2013).

2.3 Industrial Standard ANSI/ISA95

Among the various existing standards, we here chose ANSI/ISA (2005) for being well known and adopted in practice. In this standard, different control levels are defined, so that Manufacturing Execution System (MES) (level 3) processes the production performance information, and then the business level (level 4) receives this information to assist managers in making decisions. In this work, the function of level 3 is reviewed and re-interpreted to include a Sustainability Management System (SuMS) module. This module must process the data collected from the lower levels, i.e., to calculate the sustainability indicators based on information from a smart acquisition system in the PS infrastructure. In case of discrepancy in any indicator, the SuMS notifies the higher level and sends commands to lower levels in accordance to decision making procedures established by the business level. Figure 1 shows the SuMS in the ANSI/ISA (2005).

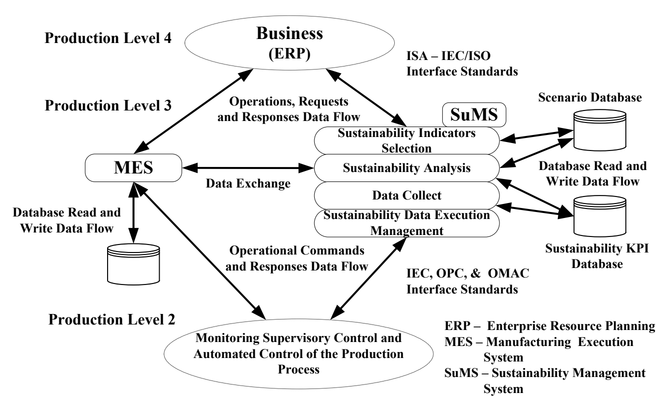

Fig. 1. ANSI/ISA-95 standard and the proposed SuMS module and communication interfaces.

The SuMS is composed of the following sub-modules:

Sustainability indicators selection, which delivers information to the upper level about PS performance and an evaluation of sustainability indicators from other systems that compose the PS to ensure compatibility among them;

Sustainability analysis, which calculates the performance of the PS based on a scenario database, data received from the MES, sustainability Key Performance Indicators (KPIs), and stored sustainability data;

Data collect, which stores the sustainability data collected directly from the PS environment;