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Key Performance Indicators of Disperse Productive System to Evaluate Performance and Sustainability

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Abstract. *In general, the performance of productive systems considers the efficient use of their technological transformation resources (e.g. machines) including information processing and handling/transportation operations. In the context of sustainability, there is no formulated criteria or rules to evaluate the performance of a productive system (PS). Thus, this paper introduces a new approach to identify and evaluate the performance indicators related to the sustainability of productive systems, specifically for geographically dispersed cases, i.e., PS in cloud computing environment. This approach is based on a framework to measure key-performance-indicators (KPIs) that evaluate the sustainability of the system. This framework considers the norm ANSI/ISA-95, and productive processes modeled in Petri net (PN).*

Keywords: *sustainability, disperse productive systems, performance evaluation, Petri net, sustainable KPIs*

1. INTRODUCTION

Currently studies have addressed the need to review the performance analysis of PS to consider alternative productivity parameters such as sustainability. Productive systems are composed by companies, facilities, and installations, i.e., entities and subsystems dispersed geographically to better explore the advantages of different locations. There are different proposes and approaches regarding specifically to the sustainability of PSs. The works of Amrina and Yusof (2011); Cannata Taisch (2010); Chen et al. (2014); Joung et al. (2013); Kondoh et al. (2008); Verrier et al. (2013) and Watanabe et al. (2014a), have indicated that:
- There are proposals for key performance indicators (KPI), although they do not address sustainability. Each company creates its own metrics and sustainability indicators for analysis and decision making, which practically precludes global assessments or comparisons among companies;
- There is no systematized procedure that considers sustainability to set criteria for the KPIs selection and calculation;
- Even though there are standards, such as ANSI/ISA-95, for setting an organizational structure for the industry to hierarchically identify the various features involved, a practical deployment of the KPIs within those organizations has not been established.

Watanabe et al. (2014b), presented techniques for process modeling to evaluate performance in sustainable PSs. Watanabe et al. (2015) has proposed a framework to evaluate a performance in disperse PS considering sustainability indicators. Thereby, this work presents a survey of factors that should be considered in order to select KPIs that value sustainability, explain the concerns assumed and main techniques to establish a systematized procedure to select and calculate the indicators. Furthermore, a general flow of information is proposed for the performance analysis and sustainability of PS, as well as a forecast of the flow implementation for disperse systems cases.

2. SUSTAINABILITY

The concept of the sustainability involves other concepts and ideas. Sustainability is a systemic term, i.e., it includes a set of factors that are responsible for maintaining a system working, producing and running processes in sustainable ways (OECD, 2011). It drives from the vision of cause and effect, WCED (1987) defines sustainable development as a process that fulfill the current needs without compromising the ability of future generations to meet their own needs.

Therefore, sustainable development seeks to improve the efficiency of any action in order to reduce environmental impacts while keeping social equity (WCED, 1987). These actions can be classified into the following groups: economic, social, environmental and technological. Although the literatures generally quote the first three groups, another was included in this work due to the fundamental role of technology in the productive sector. Figure 1 shows a diagram with all sustainability action groups.

Figure 1 - Sustainability action groups.

- Economic actions for sustainability are responsible for combating corruption, investing on infra-structure, generating jobs, sales and profits, innovating transportation, tax payments, local economy contributions.
- Social actions for sustainability are covered by law accomplishments, respect for human rights, sense of community, working conditions, supplier loyalty, and product security.
- Environment actions for sustainability are responsible for efficient usage of the energy and natural resources, biodiversity protection, reduction of waste and pollution emissions, reduction on use of hazardous materials, ecological materials and energy.
- Technologic actions for sustainability are responsible for using techniques and tools for enhancing evaluations of natural resources usage.

Achieving good indexes of these actions, guarantees high levels of sustainability to the productive system, positive impact on the environment, satisfaction of the employees and profitable manufactured products.

2.1 Sustainability Indicators

According to O'Brien (1999), indicators are qualitative or quantitative values used to evaluate some of the sustainability aspects of a system. Amrina and Yusof (2011) assess that the measure of the sustainability is more than just a set of indicators, since there are different approaches to be considered, such as the group of actions mentioned earlier, and for each group, it is possible to derive several indicators. Joung (2013) also states that the result of this measurement should support the identification of specific areas to apply enhancements related to sustainability in productive system activities.

OECD (2001) states that analyzing the data achieved and its interpretation is fundamental, since the difficulties are due to the complexity of several indicators. Inter-relationships may bring the wrong conclusions about the level of sustainability and harmful decisions of future improvements.

Figure3 shows some indicators indexes based on approaches of inputs, operations and outputs (products) of a productive system

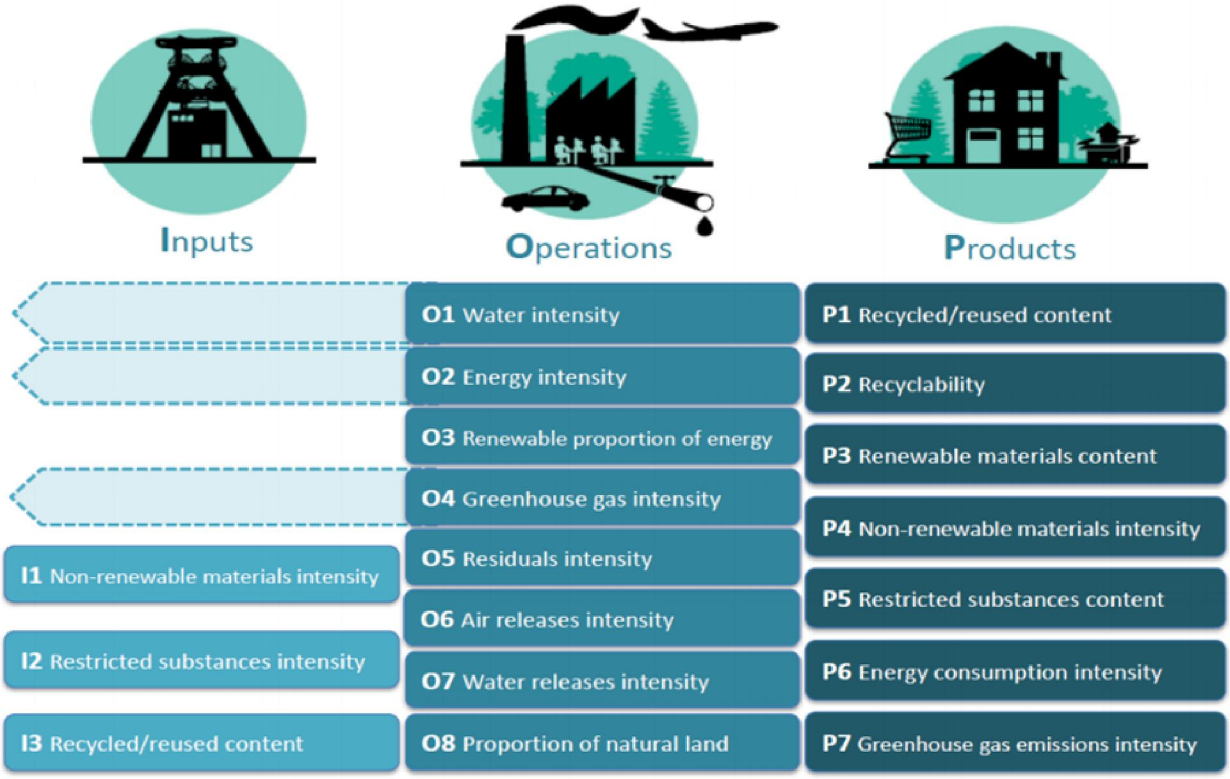


Figure 2 – Examples of sustainability indicators. Source: OECD (2001)

According to Amrina and Yusof (2011), to measure sustainability holistically, the values that represent quantification of items in assessment should be interpreted as indicators. OECD (2001) further states that the measure of sustainability involves more than just a group of indicators. Many organizations study sustainability indicators and sort them into groups according to the activity areas of the company.

These initiatives are relevant; nonetheless, the consequence is the need of the establishment of criteria standards for defining indicators, aiming to ensure both reliability and repeatability, for the calculation of the indicators, to compare the level of sustainability of products, processes and resources.

Another point is the effective use of sustainability indicators. Figure 3 presents a general procedure to employ sustainability indicators based on a list provided by specialized organizations such as OECD (2001). This procedure has to be detailed for practical use.

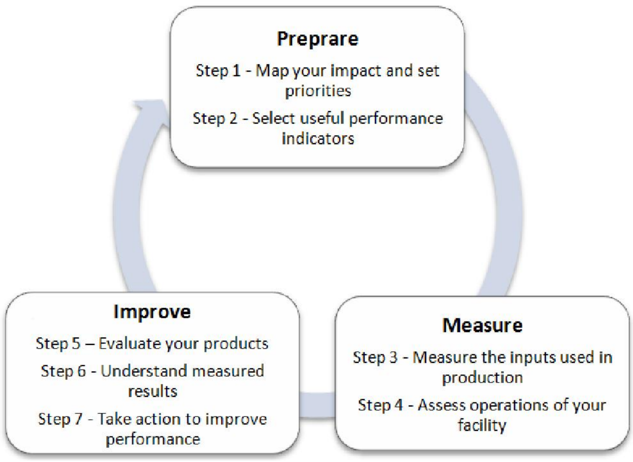


Figure 3 - Seven steps to employ sustainability indicators. Source: OECD (2001)

2.2 Sustainability of Productive System

According to Mell (2011), a sustainable productive system has the following characteristics:

•processes that minimize the negative impact on the environment,
•activities that spare natural energy,
•effective actions of security for the employees, community and consumers,
•guarantees business feasibility.

In accordance to OECD (2011), sustainable production systems are all of the productive activities that minimize the business risks for any productive operation, while maximizing the opportunities that increase the results obtained from its own processes and products.

Figure 4 depicts a diagram to show how sustainability indicators are monitored to evaluate its performance. The current work introduces a SMS (sustainability management system) module to manage all activities and keep sustainability at the expected level.

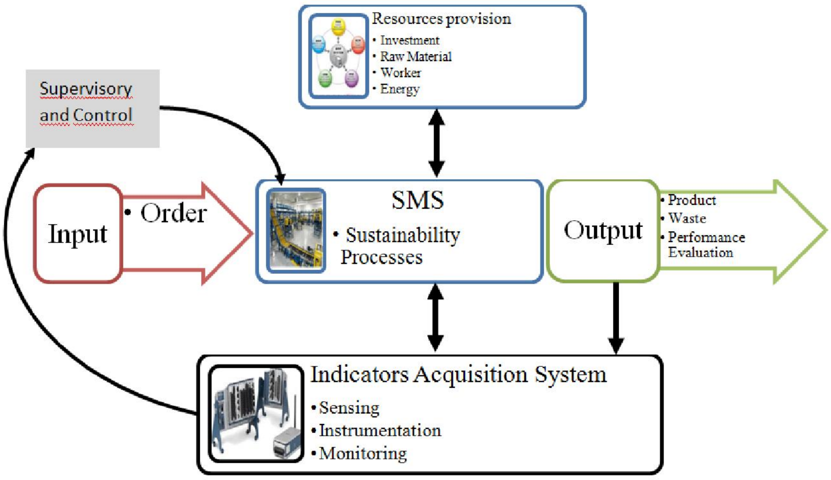


Figure 4 – Introduction of SMS (sustainability management system) module for managing all activities and keepping the sustainability of a productive system in an expected level.

3. SUSTAINABILITY PERFORMANCE OF PRODUCTIVE SYSTEMS

ANSI/ISA-95 (2005) approaches productive organization as a hierarchical structure. The top level, i.e., level 4 is called business strategic level, which executes the ERP (electronic resource planning), a business management system, typically a software of integrated applications, that a company can use to collect, store, manage and interpret data from its many activities.

At level 3 there is the MES (manufacturing execution system) – an information system used to track and document the transformation of raw materials into finished goods. It operates across multiple function areas, for example: product management definitions considering the product life-cycle, resource scheduling, order of execution and dispatch, production analysis, downtime management for overall equipment effectiveness, product quality, materials track and traces.

At level 2 is the supervisory system that ensures the performance of the productive processes in accordance to a specified production plan established at superior levels and it activates treatment procedures in the case of faults or other abnormal situations.

At levels 1 and 0 are the local controllers for each machine, sensors and actuators, the physical machines and equipment of the productive plant.

Typically, the production performance analysis is carried by MES where the production information is processed and compared to the data of the pre-established or expected values. According to the ANSI/ISA-95 (2005) norm, the following information is treated: production cycle time, the usage of the resources (machines, tools, etc.), equipment performance, efficiency of the process KPIs (key performance indicator). All solicitations from the business level should be treated by MES. The results from the production performance analysis are sent to the business level that assists managers to make decisions (see Figure 5 left side).

From the sustainability point of view, level 3 with a MES can be reviewed or re-interpreted to include a SMA module. In this case, SMS is responsible for processing the data collected from the lower levels to calculate the sustainability indicators of the productive system infrastructure. In the case of any index discrepancy SMS should act close to MES in order to indicate and notify the superior level, in addition to act in accordance to the directive established by the business level sending commands to lower levels. The business management system of level 4 along with the supervision and control systems of the lower levels do not have a part on the scope of this paper; however, it is important to consider some features of these levels since they have involvement in the sustainable and disperse SP performance analysis.

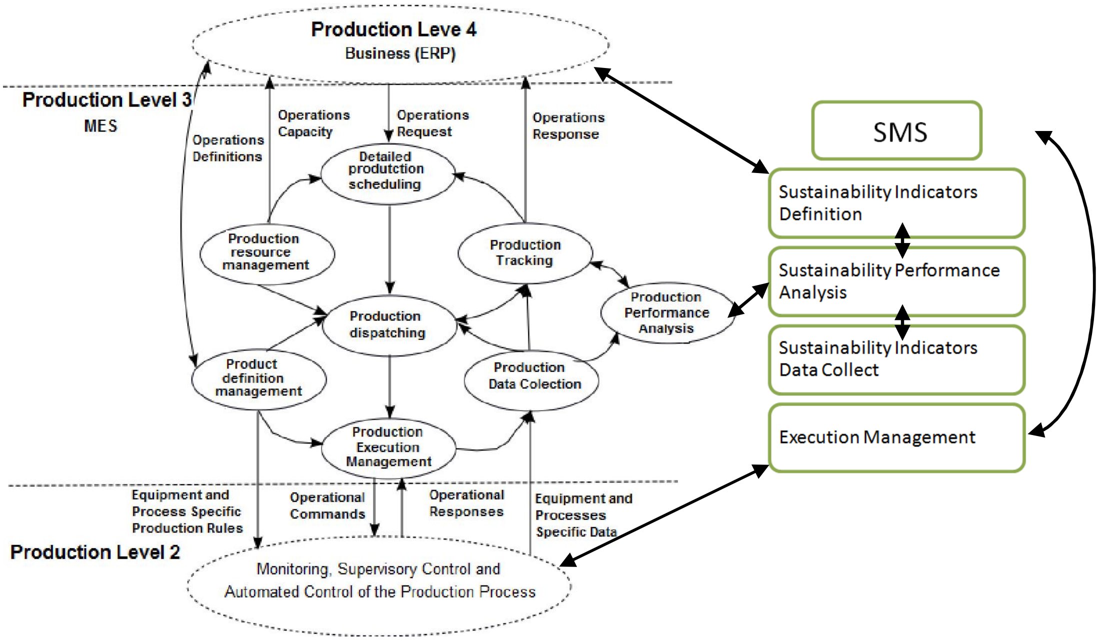


Figure 5 – ANSI/ISA-95 norm and the proposed SMS module.

The SMS is composed by:

- "sustainability indicators data collection" - sub-module that stores the productive system indicators data;
- "sustainability performance analysis" - sub-module that calculates the performance of the productive system based on data received from both the MES and the productive system sustainability indicators;
- "sustainability indicators definition" - sub-module that deliveries the interface of a performance and a evaluation of sustainability indicators from other productive systems that compose the disperse system to ensure compatibility between them;
- "execution management" - sub-module that coordinates interactions between the SMS sub-modules and equipment located on inferior levels.

3.1 Modeling Techniques

The modelling techniques can be used to predict, assess, and evaluate the performance of productive systems. Real systems have several intrinsically indeterminateness that do not permit an analytic evaluation, i.e., the instant of a fault occurrence or the instant of an operation started by a human. For these cases, simulation is an effective way of testing several situations to discover the obstacles along with the solutions to overcome them.

Based on previous works, it is assumed that dispersed productive systems can be represented as a discrete event system; therefore, Petri net is an adequate technique to model it (Miyagi, 2001; Silva, 2013). In fact, Petri net has been widely used and various extensions of this technique have been proposed according specific applications. Da Silva *et al.* (2014) have used the production flow schema (PFS) (Miyagi, 2001) technique with Petri net place/transition for systematizing the modelling procedure, performing analysis and control specification of the design of reconfigurable productive systems. Mello *et al.* (2010) also approaches the modelling of service-orientation in disperse productive systems using PFS and Petri net. In fact, these works demonstrated that this combination allows a simplified and transparent manner to develop productive process models in Petri net.

Activities carried out with PFS were by item flow (information, material, and so on).Between activities, they are clearly identified at the conceptual level (see Figure 6). For an equal PFS, it is possible to represent more than one flow, but the focus is on the general structure and the relationship among the main activities.

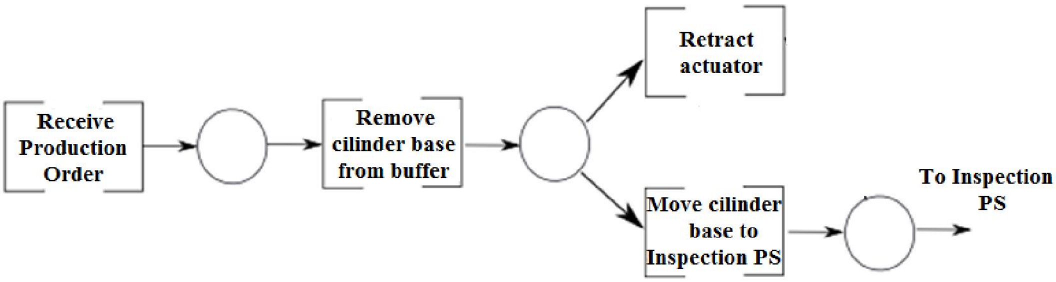
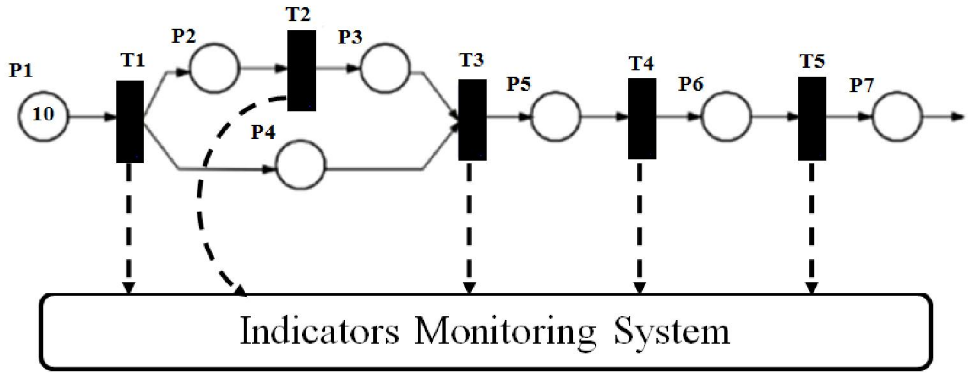


Figure 6 – Example of productive process represented in PFS.

The PFS model is gradually refined to derive models in Petri net that details the states, events and the dynamic behaviour of dispersed productive systems. Petri net is based on a sound formal definition, in addition several structural and functional properties of the models can be analysed (Murata, 2008). By simulation, the aspects where indeterminateness occurs can be analysed. In Figure 7 there is an example of a Petri net model for an activity of a productive process.



P1 is the state of the input buffer of machine 1 with 10 workpieces
P2 is the state of a workpiece waiting for machining operation
P3 is the state of a workpiece after the machining operation
P4 is the state of a workpiece at machining operation
P5 is the state of the waiting forcleaning operation
P6 is the state of the workpiece after cleaning operation
P7 is the state of the output buffer of machine 1

T1 is the start event of machine 1
T2 is the machining operation
T3 is the release for cleaning
T4 is the cleaning operation
T5 is the release from machine 1

Figure 7 – Example of a machine operation modeled in Petri net.

Beyond the Petri net capabilities of description and analysis of a productive system, there is another important feature. A Petri net model can be interpreted as a process for controlling specifications, after confirming that it had correctly described the functioning of a productive system. The implementation of this control specification is also easily accomplished with existing quasi-automatic procedures that convert Petri net models into control programs, which can be executed by commercial industrial controllers.

In this work, the PFS and the Petri net are adopted as the modelling tool to identify the production variables and parameters used for calculating KPIs. That is, models of production processes of geographically dispersed productive systems are used to generate expected KPIs, according to the guidelines of dispersed production system, established at level 4.

4. INFORMATION FLOW FOR SUSTAINABILITY PERFORMANCE EVALUATION

Figure 8 presents a basic flow of information proposed to perform evaluation of sustainable and dispersed productive systems:

1. The data consists of the specifications of physical machine operations and the types of technologies involved in the processes, which are evaluated with the standard indicators of the sustainability performance. The environmental resources data, materials and processes compose the environmental information and are previously defined.
2. The processes in the productive system are conceptually described by PFS and then detailed by Petri net models. The PN models are analyzed including the simulation of quantitative evaluation for different scenarios.

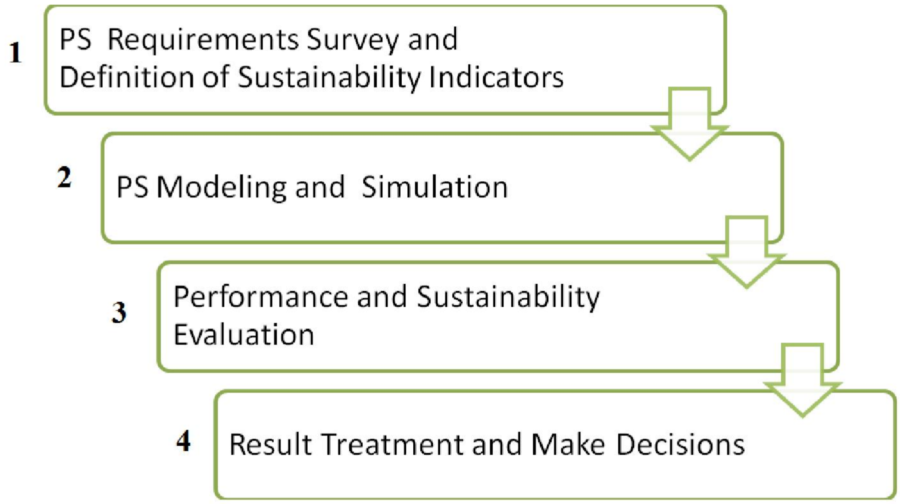


Fig. 8. Framework for the analysis procedure of performance in sustainable system.

3. The expected KPIs related to sustainability are obtained from the Petri net models, stored at SMS database and used to compare to information collected from the productive plants on-line. It is supposed that most of the information about the current status of the productive plants is available at the MES database; however, there are cases where direct communication from SMS to the supervisory level is necessary.
4. The evaluation of the differences between the expected values of KPIs and measured ones are reported to level 4; although there are cases where some activation commands are previously established (evidently derived from decision of an upper level).In this case, a message must be send to MES to update the tasks to be carried out in the productive system.

5. ENVIRONMENT OF DISPERSED PRODUCTIVE SYSTEM

The application of the proposed information flow for a dispersed productive system is depicted in Figure 10. The sustainability performance indexes are requested by the SMS module from the MES of each productive system. To explore the disperse nature of the system the cloud computing environment with cloud storage resource is considered (Wu *et al*, 2013; Ferreira *et al*., 2013; Jeong and Lee, 2014).

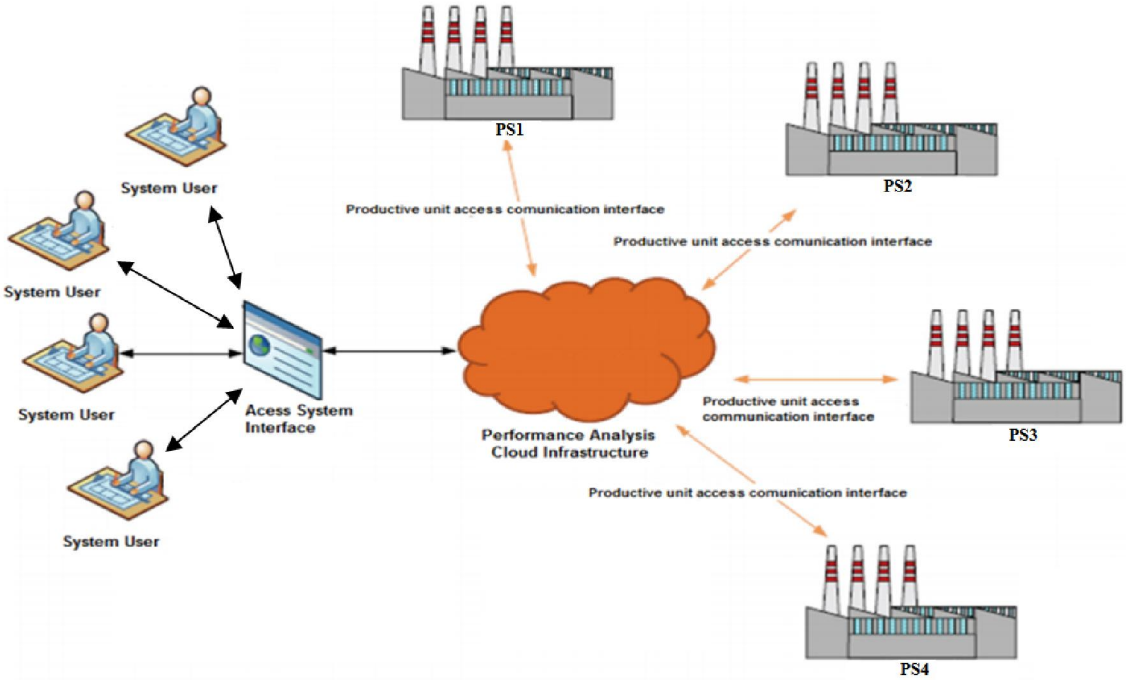


Figure 10 - Disperse productive system and cloud computing environment.

The users (system manager, engineer and production manager) are able to access all data of the productive system at business level interface, to evaluate the performance and simulate new scenarios to improve the productive system. At this environment, all production and sustainability data are accessed from wherever they are via Internet.

6. CONCLUSION AND FURTHER WORKS

To evaluate the performance and sustainability of an industry it is important to consider the ANSI/ISA-95 (2005) norm that recommends a structure of hierarchical decision/control levels. However, the norm does not explicitly consider how to treat sustainability indicators. Therefore, this work presents a re-interpretation of the norm at level 3 to include MES (management execution system) and a module called SMS (sustainability management system). This work explains a systematic way to calculate performance evaluation of sustainable production systems by exploring the modelling power of Petri net and its extension PFS (Production flow schema). The general information flows for performance evaluation of sustainable production systems is proposed and its application for the dispersed system case is explained. Further works will evaluate the proposals in study cases.

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