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Sustainable Operations Management for Industry 4.0 and its Social Return

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Abstract: In today's industrial environment, where concepts of smart factories are consolidating their application in companies, it is still necessary to approach management decision making from a perspective that encompasses all aspects of sustainability without losing sight of the social return to which they must contribute. In order to obtain a reliable prediction, of the operation of a Sustainable Manufacturing System (SMS) and its Social Return (SR), this paper develops a methodology and procedures that allow predicting the system performance as a whole. This will allow us to assist management decision making in industries 4.0, supported by multi-criteria methods in knowledge management, simulation, value analysis and operational research by means of:
a) Study the economic, social and environmental impacts in the organization and management of the efficient operation of an SMS with the selection of strategies and alternatives in production chains to minimize and / or mitigate environmental and labor risks.
b) Encourage of industrial symbiosis or eco-industries networks that create opportunities increasing eco-efficiency and the positive social return of production systems.
This proposed methodology will facilitate changes in the structure of production systems in order to implement industry 4.0 paradigms through facilitator technologies such as simulation and virtual reality.
This framework will allow Small and Medium Enterprises (SMEs) and other companies to address the decision-making activities that improve the economic-functional efficiency, which will lead to reduce the environmental impact and increase the positive social return of certain production strategies, considering working conditions.
The proposed approach went validated, in the area of the Euroregion Galicia North of Portugal, to favour the implementation of the decision-making through the Industry 4.0 Technologies.

Keywords: Optimization Methods and Simulation Tools; Sustainable Manufacturing; Industry 4.0, Social Return, Sustainability Index Function, Artificial Intelligence, Industrial Production Systems, Social Impact of Automation

1. INTRODUCTION

In order to obtain a reliable prediction of the operation of a Sustainable Manufacturing System (SMS) and its Social Return (SR), it is necessary taking into account local quality failures and problems that impact on the production efficiency of the process. The methodology and procedures proposed allow predicting the system performance as a whole unit, making diagnoses, identifying problems in the production chains and improving the management conditions in Industries 4.0. To accomplish that we rely on the support of a body of knowledge comprising multicriteria Methods in the management of knowledge, operations, value analysis and operational research applied to:

- Study the economic, social and environmental impacts viability in the organization and management of the efficient operation of an SMS with the selection of strategies and alternatives in production chains to minimize and / or mitigate environmental and labour risks.
- Promote industrial symbiosis or eco-industries networks that create opportunities increasing eco-efficiency and the positive SR of production systems.

1.1 Objectives

The main objective of the research here reported is to cause changes in the production systems structure to minimize or eliminate the negative effects associated with energy consumption and the generation of waste and stimulate good practices that generate positive social returns with the implementation of efficient Design and Manufacturing Processes 4.0, taking into account the financial, social and environmental dimensions.

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1.2 Why the need of a new focus?

In order to achieve these changes, it is necessary to develop methodologies and procedures to carry out the change or the digital transformation in companies, in particular in SMEs, increasing the efficiency of the production chain and creating the conditions to have an Integrated SMS. The conceptual model is based on the realization of a set of solidly interrelated phases for:

- Calculation of the production efficiency and establishment of an Expert System architecture with a database that includes:
  - Sustainability and SR indicators.
  - The associated costs and the efficiency of the process operation, of energy source and consumption, of waste treatment and of the social and environmental impacts.
- Development of a support system for decision making based on a Discrete Event Simulation (DES) model.
- Application of Life Cycle Analysis (LCA), developing a structure that incorporates decision making paths
- Implementation of an Economic-Functional Index to link with SR evaluation.

The concern with SR issues has empirical support. In fact, findings from various studies have concluded that the alignment of SR practices with firm's business operations increases the overall firm performance (Kanwal et al. 2013, Lin et al. 2015 and Handayani et al. 2017). Analyzing data obtained from more than 400 companies in Central Java, confirmed that Corporate SR has a positive influence on social collaboration initiative and that the latter has a strong influence on the firm performance, as well as on the adoption of green innovation, spread all along the strategic decision making of the companies.

2. METHODOLOGY

In some studies, much attention has been given to the cost configuration of production lines considering three aspects of sustainability. For example, optimization models directed to the production flow of multistage/ multiproduct production lines using simulation were developed (Ares et al. 2012, Ferreira et al. 2012 a, b, c). These studies produced a sustainable indicator of economic and functional efficiency for a production line or process. Our Sustainability Index Function (SIF) incorporates the costs related to the three fundamental aspects of sustainability: production, environment and society, and so we defined a function of integration of these elements, as follows:

Sustainability Index Function = [(Productivity Coefficient) × (Costs of Production Indicators)] + [(Environmental Coefficient) × (Cost of Environmental Indicators)] + [(Social Coefficient) × (Cost of social Indicators)]

$$SIF = (\alpha \times EFI_P) + (\beta \times EIF_E) + (\gamma \times EIF_S)$$

Succinctly it is now presented the main constituents of each term. The complete formulation and variables identification were presented and described (Naderi. M and Ares. E, 2017). Thus, an economic index is obtained to help in the decision-making process, based on the most suitable criteria or alternatives for each moment of production. So that, it takes into account the results of the production system simulations, along with the calculation of the coefficients of importance of each aspect in the company obtained through decision-making methods based on expert opinions.

EIF_P = (Cost of Fixed Production) + (Cost of machine non-use) + (Cost of manipulation) + (Cost of storage inactivity) =

$$[(\sum_{j=1}^{n} Nij * TPij * CFij) + (\sum_{j=1}^{n} CNUj * TIj) + (CPFDD*TSA) + (\sum_{j=1}^{n} Bij * TMij * CMij) + (\sum_{j=1}^{n} CNUBj * TIBj)]$$

EIF_E = (Cost of Materials, Energy and Water) + (Cost of Solid Waste, Emissions and Residual Water) =

$$[(\sum_{j=1}^{n} Mij * CMij) + (\sum_{j=1}^{n} Pij * TP_{ij} * CPij) + (\sum_{j=1}^{n} PEij * CPE) + (\sum_{j=1}^{n} WCij * CWC) + (\sum_{j=1}^{n} Wij * CWij) + (\sum_{j=1}^{n} EAij * CEA) + (\sum_{j=1}^{n} WPij * CWP)]$$

EIF_S= (Cost of Employee) + (Cost of Supplier and Customer) =

$$[(\sum_{j=1}^{n} NTj * HTP * CHTP) + (\sum_{j=1}^{n} NTj * HFC * CHFC) + (\sum_{j=1}^{n} NTj * CMEPI) + (TIO * CPS) + (\sum_{j=1}^{n} CIR) + (NQC * CQC)]$$

The structure of our methodology comprises the following phases:

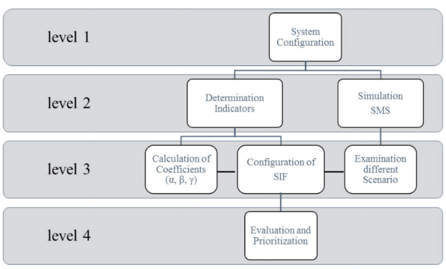
The first phase addresses the production line specifications or characteristics of the studied manufacturing company. In order to the implementation of the methodology and for sensitivity analysis, must be chosen a manufacturing company or a production line with full details and database.

The second phase is composed of two main parts that in the first part determined the effective indicators in the triple aspects of the production process and, the second part simulated the studied production line. The simulation software used for this purpose is our Norlean Analyser Operation (NOA - http://norlean.com/en/).

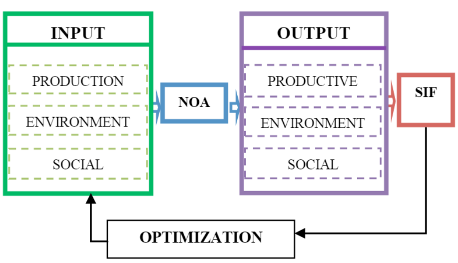
The third phase is related to the calculations of the qualitative and quantitative data gained from previous phases. This phase is formed of three main sections, Which include the calculation of the coefficient for each aspect of sustainability through multi-criteria decision-making methods, configuration of the SIF in the studied company based on the cost indicators of sustainability aspects, and at last the simulated production line is with NOA is compared to different strategies or scenarios; the data obtained from the simulation is used at SIF for evaluation of the production line.

The final phase is related to the evaluation of sustainability and SR. the SIF results obtained from the proposed methodology are assessed and the strategies applied to the sustainability domains in the studied company are prioritized.

The basic architecture of proposed methodology is depicted in figure 1. Already the methodology presented implemented with simulation software such as ARENA and SIMIO that are generally used in large companies (Naderi M., Ares E. et al 2017). Now this paper presents the implementation of the proposed methodology with NOA for SMEs, since such implementation is easier to manage by the final user, less costly and allows evaluating other factors related to the environment, working conditions and the social return of innovations and technological developments, incorporating artificial intelligence.



(a)



(b)

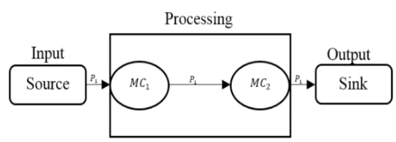
Fig 1. a) The general view of the methodology layers and b) A perspective of the presented methodology implementation

It is hoped, therefore, to integrate knowledge in the evaluation of investment projects in R + D + I, promoting a broader perspective that covers all the interested parties in this process. It involves flows of data and their monitoring, requiring the digitization of manufacturing processes and communication flows of data, in predefined formats, for easier integration. It is also necessary to take into account social responsibility issues and use key performance indicators that suitably incorporate and assess the social effects of industry 4.0 projects.

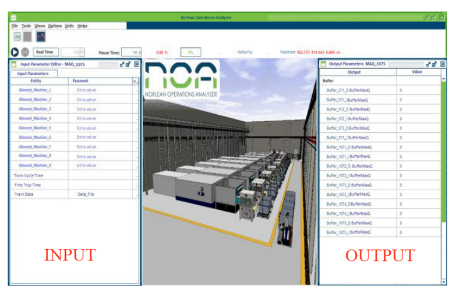
It is thus necessary to increase the digitalization of manufacturing processes and supply chains, facilitating communications between humans, machines and products, thus allowing real-time access to information, products and their production during their life cycle.

With the purpose of increasing this implementation, a disruptive software tool for Process Simulation with Discrete Events (DES) has been developed and based on virtual reality, NOA. The aim is to use the AI as a complement to the decision making in the manufacturing area (Santos et al. 2017, Yin et al. 2013). It could be a tool for optimizing the business models and implementing the transformation into digital industry 4.0, according to Salguero and Ares (2017).

The validation of the presented methodology was performed in several different production lines, and the obtained results analyzed and compared. This research validation is illustrated with the results of one of the production lines used, a specific production line in an injection plastic SME, presented as an example in figure 2.



(a)



(b)

Fig 2. a) A simple logical model of production line b) the application of NOA tool

2. 1 Methodology Strategy.

The strategy is based partly in the differentiation of the solutions provided to each company's clients, to arrive at a customized solution within the possible options that they can choose, always within the scope of manufacturing.

The core is in the optimization of the manufacturing lines through the analysis of its operations. In some way, it could be understood that the company adopting this approach will be able to help its customers to compete on costs, but it should not be confused with optimizing and reducing costs depending on the combinations of sales and production.

In the current environment companies, have many different tools such as Excel, ERPs, MES and etc. That can produce an excess of data to analyze, calling for digital analytics methods to produce meaningful knowledge for increased productivity.

It must be said that NOA tool simplifies the use of complex technologies, in which the technical knowledge of the user is reduced to the understanding of his/her business and allows changing in a very simple way the scenarios he/she wants to analyze. That is, NOA gives the user a virtual replication of a factory, a machine or a process, specifically built for him and extremely easy to use and manage.

2.2 Technologies used as a mix.

The Industry 4.0 Technologies used in this case as a mix are: Industrial Internet of the things (IIOT) + Big Data (BD) + Discrete Event Simulation (DES) + Virtual Reality (VR) + Augmented Reality (AR) + Artificial Intelligence (AI).

The methodology starts with the analysis of a large amount of production data that we turn into statistical models by stages and later we build the algorithms that define the production model that we connect with the profit and loss account. It is thus created the full business model of an industrial company.

This data is collected through an ERP or a MES and NOA can work in real time or with projections. As a summary, the objective is to convert Big Data into smart data with meaning and reflected in Key Performance Indicators (KPIs). For the analysis, the tool relies on the VR and AI, which help the user analyze operations in a faster way.

2.3 Potential AI Applications

The idea about this is reaching the application level of AI in the following stages of NOA development, showing the application in Sustainable Manufacturing Systems (SMS) and Social Return (SR) incorporation through the Sustainability Index Function potential use. With the virtual reality or simulation, modelling is possible to generate multiple models, scenarios and profitability of an industrial company and its outputs with inputs depending on sales, raw materials, production, human resources, etc. If a layer of AI is given to these systems, allowing the user to make the right decisions at the right time, a partnership between humans and machines will be created, therefore, making them work together, thus creating what is known as collaborative intelligence.

2.4 Social Responsibility and Methodology Congruence with the PIC / RIS3T

Over time, social responsibility has been gaining importance and companies are trying to find a proper balance between economic profitability and social responsibility. In order to find out what the major policies, strategies and practices that have been developed regarding Corporate Social Responsibility (CSR) and how to evaluate them, Galician companies created the Permanent Observatory for CSR in 2010 (Fernandez et al. 2015). At present, the transition to Design and Manufacturing 4.0 by Alexandre et al (2017) and Santos et al (2017), is a reality in the Euro region Galicia-north of Portugal. The adoption of this paradigm shift still requires research to advance the development of knowledge and its application, since more and more companies and professionals need the right knowledge.

The development of tools and procedures to facilitate multi-criteria decision processes and pro-active attitudes, in order to identify the associated risks and mitigate the negative impacts on economic, environmental and social development from the Analysis of Manufacturing Processes, allows greater efficiency on the improvement of the corporate sustainability in the Companies of the Euro region since it is promoted:

- Training of human resources at the academic level, including researchers and professors in the questions related to the management of Sustainable Production and the Efficient Use of Resources in the Euro region and in the qualification of technical personnel with training in sustainability and practices of cross-border cooperation in local communities, increasing the social dimension and sustainability.

- Generation of doctoral theses, doctorate and postdoctoral research in the subject matter of management of sustainable production and efficient use of resources in the Euro region, taking into account the supply chain, reverse logistics, waste production, reduction of environmental and labour risks, as well as economic costs.

- The thematic work meetings must be carried out in parallel with the teaching activities of the Master's Degrees, in order to reduce operational costs and relocation among the members and at the same time to keep plans of action and dynamics.

- The design of tools for the evaluation and management of Sustainable Production and Efficient Use of Resources, initially in companies with the greatest environmental, social and economic impact, to promote changes in the patterns of production, consumption and use of resources and contribute to the economic development and sustainable social return.

- Provide relevant information to those responsible and interested parties of the SMEs of the Euro region and thus analyse, evaluate and redirect their organizational performance with their social and environmental implications.

The definition of this new conceptual model (Cunha et al. 2009, 2011, Fernandez et al. 2011, 2015), which allows measuring and evaluating the economic and social return of investments in R + D + I activities in Galicia and northern Portugal encompasses a vision or new approach. To undertake the empirical study, a selection of indicators directly related to the measurement of the social return of R&D programs was made. This selection of indicators was based on the literature and on the data and information available from the Spanish Observatory of Invention and Knowledge (ICONO). The selected categories of indicators were Employment; Working conditions; Learning and growth; Social return vs. financial return; Environmental Effects; and Investment rates. The concretization of projects that enable us to ensure the smart, sustainable and inclusive growth proposed by the European Commission in its Horizon 2020 strategy and in the GALICIA-NORTE DELEGATION INVESTMENT PLAN OF THE GALICIAN-NORTH PORTUGAL EUROSYSTEM (2014-2020) are favoured under the PIC/RIS3T.

According to this investment plan, there is a need to increase the investment of companies in these regions in R + D + I activities (E1.P1 and E1.P2 of the aforementioned document). These R+D+I investment impacts should be measured not only by the economic benefits that directly increase companies value, but also by the existing infrastructures and by the advantage of human capital, as well as the broader impacts of the spectrum that benefit the entire community, measuring the social return of investments.

In the last decades, the greater competition between companies, the reduced life cycles and the globalization of the markets demonstrate the necessity to measure the return of the enterprise investment in R + D + I. For this, there is an urgent need for companies to include non-financial criteria in their evaluation of R+D+I investment decision-making processes, and a broader perspective should be adopted, taking into account not only the strictly economic-financial return of the company, but also the social return (or social impact), to the community where the company is inserted.

In this way, it is understood that R + D + I managers of public and private entities need new tools to support the decision in this type of investment, since they should adopt this broader perspective of social return evaluation. This argument is linked to the Horizon 2020 growth strategy defined by the European Commission, which aims to promote development from a smart, sustainable and inclusive economy that allows the generation of high levels of employment, productivity and social cohesion.

Nowadays, the manufacturing enterprises should be considering the costs associated with natural resources consumption -energy, water and materials-, the manufactured wastes -solid, wastewater and emissions- and negative impacts on society and so on, as costly important factors. Simulation and complementary digital tools can be used to support decision-making and to evaluate the impact of various opportunities for improvement. Ideally, the simulation model can be used to evaluate the alternatives. Discrete-event simulation has proved to be robust as a tool to help quantify the benefits of lean manufacturing.

According to the report "Oportunidades Industria 4.0 en Galicia", the percentage of the implementation of the modelling, simulation and virtualization technologies of processes in the environment of Industry 4.0 is 21% and the forecast of implementation is 23%. It is necessary to be able to analyse the implementation of business models, through advanced digital analysis and 3D simulation technology.

3. CONCLUSIONS

In this research Methodologies, tools and procedures were developed for implementation in SMEs, towards digitization, making use of Simulation Models and Artificial Intelligence. These serve to improve economic and functional efficiency of manufacturing processes in 4.0 SMEs, considering the environmental impact, working conditions and the Social Return.

Future work will be focused in implementing the methodologies proposed in different SMEs helping them to evolve steadily towards digitization of their production processes, increasing profitability and welfare. Simultaneously, the set of implementations will provide information for the identification of common practices, contributing towards the establishment of a set of good practices for benchmarking assessments.

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