Sustainable manufacturing systems – a simulation model

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Abstract. Connecting companies to the paradigm of climate change leads to the creation of sustainable production systems. In this context, new approaches to processes allow the definition of sustainable manufacturing systems. The sustainability of manufacturing systems is an important aspect in order to insure the competitive power of enterprises. In this respect, the manufacturing systems must take into account economic factors, environmental concerns and social directions. Decisions regarding manufacturing development, optimization, or reorganization are driven by many factors and are often costly, with the benefits hard to justify before implementation. This paper describes an agent-based model simulation that analyses the behaviour of a sustainable manufacturing system.

1. Introduction

A sustainable manufacturing system (SMS) is a combination of the waste reduction as Lean Manufacturing principles, reduced-recycling-reusing as Green Manufacturing principle, Total Quality Management, and Corporate Social Responsibility [1, 2].

This paper is aim at developing a simulation model that will be able to obtain an optimal configuration of SMS considering both economic criteria and environmental responsibilities, reflected in minimizing the total cost, total energy consumption and CO2 emissions.

Hence, a feasible solution to the problem of SMS, its modelling, and implementation the model the Anylogic simulation environment, so that the application of the optimization can be done quickly [3].

The present paper is structured as follows: after a brief presentation of the theoretical aspects of a multimethod simulation model, we will discuss the development of an SMS, considering the following variables: suppliers s, the factory f and the warehouse w.

The model aims to determine the optimal solution taking into account the three objective functions, namely the investment cost required to configure the manufacturing system, the total energy consumption of the manufacturing system and the total CO2 emissions. The following chapter presents the solving methodology using the Anylogic environment [4]. The last chapter describes the conclusions related to the simulation model and possible further development.

2. The multimethod simulation model

Systemic methods are used to understand the organization of data. They present real-world objects in the form of entities. The relations between them are represented in the form of associations.

In order to implement the simulation it is necessary to do the modelling of the real-world entities. To make them into a single, efficient, and manageable multimethod model that represents the
behaviour of the whole system, we should do a few more things. The simulation environments consists of three modelling methods [4, 11], respectively agent-based modelling dynamic systems, and discrete events.

Each method supposes a certain of level of abstraction. When the simulation requires a high degree of abstraction, the simulation environment can use dynamic systems.

As a research direction, the SMS model in this paper hereby described can be integrated into a supply chain, being thus connected to both the suppliers' network and the customers.

The conceptual model describes how a factory makes a product based on the resources provided by different suppliers. A factory can process raw materials supplied by different suppliers. The choice of suppliers is based on their production capacity and the ability to deliver current orders. This approach suggests the use of the model based on agents with a certain level of intelligence [4, 8].

![Conceptual model](image1)

**Figure 1.** Conceptual model.

Customers request a product at the factory, and pick up the available items at the current time. The excess of demand over supply is lagging behind (figure 1).

Separate data sets for costs, energy consumption and carbon emissions will be associated to the simplified manufacturing system. The simulation results will be retrieved via Excel files.

![Factory as an agent](image2)

**Figure 2.** Factory as an agent.
A factory is modelled as an agent (figure 2). They interact in an environment by sending messages to each other. There are two types in an environment when sending messages to each other.

From the perspective of an SMS, a product is made based on resources [5, 6], is processed on specific machines, and in the end other resources are released [7, 8].

Under the conditions of the designing of a sustainable manufacturing system, the solutions that can be obtained will have the following characteristics:

• Energy consumption and CO2 emissions [9];
• Optimal number of machines [10];
• Optimal materials flow in the manufacturing system [11, 12].

Generally, the model uses a stationary policy. The cost, energy consumption and carbon emission parameters are associated with ordering, manufacturing, keeping products and having a backlog. The simulation output includes the structured average daily cost, energy, emission produced by all components of the supply chain.

![Diagram](image.png)

**Figure 3.** AB and SD design.

Inside the factory agent is represented a diagram of the dynamics of the system (figure 3). It represents the production process.

Therefore, this model is a multimethod one, based on Agent and System Dynamics [4].

There are two types of processes and corresponding messages: ordering and shipping. A black line between producers indicates that a producer is waiting for a supply from another producer (figure 4). The width of the line indicates the size of the command [3, 7].
Parameters variation experiment performs several single model runs varying one or more parameters.

Figure 4. Simulation scene.

Figure 5. Running simulation.
Function defined for finished goods is described as follows:

```java
if (factory.size() != 0) {
    double m = 0;
    for (int i = 0; i < factory.size() - 1; i++)
        m += ((Factory) factory.get(i)).finishedGoods;
    return m;
} else
    return 0;
```

Function defined for raw material inventory is described as follows:

```java
if (factory.size() != 0) {
    double m = 0;
    for (int i = 0; i < factory.size() - 1; i++)
        m += ((Factory) factory.get(i)).rawMaterialInventory;
    return m;
} else
    return 0;
```

Using this experiment one can compare the behaviour of model with different cost, energy, and emissions values (figure 5). These parameters are associated with both waiting in the queue before the station, and with the processing. Each minute of waiting and each processing operation have a unit cost.

The system collects the values of cost, emissions and energy assigned to the parts that exit the system in a time series dataset.

3. Conclusion
Simulation, as an essential tool for the manufacturing system analysis and the impact of system changes evaluation, can assure informed decisions.

Specific processes and strategies can be modelled and simulated in manufacturing simulation software. This enables effective analysis, and provides an efficient way to experiment and reduce the costs of testing in the real world. Process simulation software, AnyLogic gives the power to get the most from your manufacturing [4].

Using process simulation software is key to the detailed analysis and effective operation of your organization.

By analysing the proposed optimization model, we can conclude that, this simulation model can determine the inventory level for the manufacturing system that result in minimum cost, energy consumption and carbon emission. The model includes a simulation experiment where ones can set up the parameters manually, and the automatic optimization experiment.

The mathematical and simulation model thus developed can be used to obtain an optimal configuration of SMS considering both economic criteria and environmental responsibilities, reflected in minimizing the total cost, total energy consumption and CO2 emissions.

As a future direction of development, the simulation model will be extended with a detailed manufacturing module in the Anylogic environment [4], so that the application of the optimization can be done quickly.

The simulation model may be generalized at a complex manufacturing sustainable systems.
References

[1] Nujoom R A O, Mohammed A M and Wang Q 2019 Drafting a cost-effective approach towards a sustainable manufacturing system design *Comput. Ind. Eng.* **133** 317

[2] Nujoom R A O, Wang Q and Mohammed A 2018 Optimisation of a sustainable manufacturing system design using the multi-objective approach *Int. J. Adv. Manuf. Tech.* **96** 2539

[3] Tilină D I, Zapciu M and Mohora C 2015 A system model to integrate the “Green Manufacturing” concept in Romanian manufacturing organisation *IOP Conf. Ser.: Mater. Sci. Eng.* **95** 012128

[4] www.anylogic.com. Accessed: april 2020.

[5] Mohammed A 2020 Towards ‘gresilient’ supply chain management: A quantitative study *Resour. Conserv. Recy.* **155** 104641

[6] Zindani D, Kumar K and Davim J P 2020 Sustainability Manufacturing Systems Design *Hashmi, S. and Choudhury, I. eds. Encyclopedia of Renewable and Sustainable Material Elsevier* 5 512

[7] Ikumapayi O M E T, Akinlabi P, Onu S A, Akinlabi M and Agarana C 2019 A Generalized Model for Automation Cost Estimating Systems (ACES) for Sustainable Manufacturing *J. Phys.: Conf. Ser.* **1378** 032043

[8] Foit K, Banaś W, Gwiazda A and Hryniewicz P 2017 The comparison of the use of holonic and agent based methods in modelling of manufacturing systems *IOP Conf. Ser.: Mater. Sci. Eng.* **227** 012046

[9] Tamás P, Illés B and Dobos P 2016 Waste reduction possibilities for manufacturing systems in the industry 4.0 *IOP Conf. Ser.: Mater. Sci. Eng.* **161** 012074

[10] Henao-Hernández I, Solano-Charris E L, Muñoz-Villamizar A, Santos J and Henríquez Machadoet R 2019 Control and monitoring for sustainable manufacturing in the Industry 4.0: A literature review *IFAC PapersOnLine* **52** 195

[11] Peter O and Mbohwaet C 2019 Industrial Energy Conservation Initiative and Prospect for Sustainable Manufacturing *Procedia Manufacturing* **35** 546

[12] Huang A, Badurdeen F and Jawahir I S 2018 Towards developing sustainable reconfigurable manufacturing systems *Procedia Manufacturing* **17** 1136